‘Mauka makai’ ‘Ki uta ki tai’: The ecological and socio-cultural values of estuarine shellfisheries in Hawai`i and Aotearoa New Zealand.

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Abstract

Estuaries rank among the most anthropogenically impacted aquatic ecosystems on earth. There is a growing consensus on anthropogenic impacts to estuarine and coastal environments, and consequently the ecological, social, and cultural values. The protection of these values is legislated for within the U.S. and Aotearoa New Zealand (NZ). The respective environmental catchment philosophy ‘Mauka Makai’ and ‘Ki Uta Ki Tai’ (lit. *inland to sea*) of Indigenous Hawaiian and Ngāi Tahu forms the overarching principle of this study. The scientific component of this study measured shellfish population indices, condition index, tissue and sediment contamination which was compared across the landscape development index, physico-chemical gradient and management regimes. Within the socio-cultural component of this study, Indigenous and non-Indigenous local residents, ‘beach-goers’, managers, and scientists were interviewed towards their perception and experience of site and catchment environmental condition, resource abundance and changes, and management effectiveness of these systems.

Both the ecological and cultural findings recognised the land as a source of anthropogenic stressors. In Kāne`ohe Bay, Hawai`i, the benthic infaunal shellfish density appears to be more impacted by anthropogenic conditions compared with the surface dwelling Pacific oyster, *Crassostrea gigas*. The latter was indicative of environmental condition. Although the shellfish fishery has remained closed since the 1970s, clam densities have continued to decline. This is the first *C. gigas* population survey, showing variabile distiribution, the highest abundance located at urban residential piers. The clam-bed sediment contamination concentrations exceeded the Sediment Quality Guidelines and were comparable to findings in the U.S. This requires further investigation by local authorities. Lower *C. gigas* condition index was associated with elevated tissue arsenic concentration.

Native fish and plant life (limu) rather than shellfish were important species to harvest/gather in Kāne`ohe Bay. However, active shellfish culturing was currently being trialled or commercially operated, while the recreationally fishery has been closed for > 30 years. Introduced fishery pressures and landscape development were highlighted as key issues in the Bay. Kānaka Maoli fishery practices and traditional management systems were responses to perceived decline in native fisheries. Extensive restoration efforts were occurring in Hawai`i that may aid to reduce anthropogenic input. Interview analysis was limited by low sample size. ‘Mauka makai’ and local fishery-ecology management systems were recommended by more experienced (>20 yrs) Indigenous and non-Indigenous participants.

In Canterbury, New Zealand, the New Zealand littleneck clam, *Austrovenus stutchburyi*, was indicative of environmental condition, while the pipi, *Paphies australis*, was only abundant at one site, and the dredge oyster *Tiostrea chilensis* were sparse and without individuals of harvestable sizes. The *A. stutchburyi* condition index was positively influenced by salinity and negatively with tissue Metal Pollution Index (MPI), tissue *E. coli*, and sediment MPI. The *A. stutchburyi* density negatively correlated with both tissue and sediment metal concentrations. Additionally, tissue inorganic arsenic and tissue *E. coli* concentrations exceeded the guidance for human consumption. The latter exceeded multiple times, and included low salinity sites at the urban and high-intensity rural estuary. Sites of elevated contaminants shared similarities that can further guide monitoring and restoration efforts.

The top environmental indicators provided by interview participants aligned with the known global stressors within estuaries. The values of Ngāi Tahu were compromised more often than other cultural affiliations in New Zealand. Ngāi Tahu fishery practices and restoration efforts have responded to perceived decline in native fisheries. 'Inland-to-sea' management systems were recommended by Indigenous and non-Indigenous environmental specialists. The anthropogenic impacts of stressors on estuarine systems requires ongoing assessments of environmental condition, and effects on ecological and cultural values.

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Mō apōpō, ā mō kā uri whakaheke[1] (Ngāi Tahu)

He ali`i ka `āina, he kauwā ke kanaka[2] (Pukui 1983) Hawai`i

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Ngā mihi nui kia koutou katoa.

[1] "For tomorrow, and for our descendants who follow"
[2] "The land is a chief; man is its servant"

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Preface

Writing Convention

<u>Capitalisation of Group Entities</u>

Indigenous group entities are capitalised including Indigenous People(s), Kānaka Maoli, Māori, Tangata whenua and Mana whenua. This is to provide these entities importance to that of ethnic groups: for instance, English, American; as well as distinguish between the normalised cultural group European or Western compared to Indigenous.

<u>Not italicising `Ōlelo Maoli and Te Reo Māori</u>

I ka `ōlelo ke ola, i ka `ōlelo no ka make.

In the language is life, in the language is death.

Traditional Hawaiian Proverb (Meyer-Ho`omanawanui 1999).

`Ōlelo Maoli, the language of Kānaka maoli (native Hawaiians), and Te Reo Māori the language of Māori, Tangata whenua, Mana whenua, are not treated as 'the other' cultural language and is purposefully not italicised in this thesis. Both the Hawaiian and Māori language were banned from public schools, as part of the systematic removal of Hawaiian people and culture from their home lands (Ho`omanawanui 2016). Kānaka have their own language, cultural and social systems existing through over 200 years of colonisation and oppression (Meyer-Ho`omanawanui 1999). This research has an Indigenous Peoples focus, and is concerned with privileging and highlighting Kānaka Maoli and Māori voices, and by extension `ōlelo Maoli, and te reo Māori.

Mātauranga Māori has been eroded through the educational policies and the Tohunga Suppression Act 1907 that disallowed conversing, practices, and thus transferral of knowledge systems over generations. Te Reo Māori evolved from the ecosystem, as captured within the name, Tangata whenua, people of the land, the environment shaped Māori existence, and thus knowledge system. This knowledge was both intricate in detail and extended spatio-temporally.

Glossary

Environmental science and socio-ecological systems

Bioindicators	Used to reflect changes in systems at higher levels of biological organisation. For biomarkers to be considered bioindicators they must be causally linked to ecologically relevant endpoints (Adams 1990).
"Biological indicators approach"	Involves measurement of a suite of selected stress responses at several levels of biological organisation to assess sublethal stress effects, to give early warning of stress and to obtain insights into causal relationships between stressors and effects manifested at higher levels of biological organisation.
Biophysical	The biotic and abiotic surrounding of an organism or population, and consequently includes the factors that influence their survival, development, and evolution.
Ecosystem services	The direct or indirect contributions that ecosystems make to the well-being of the human populations.
Enterococci	A genus of gram positive bacteria that resemble streptococci that occurs naturally in the intestine, but cuases inflammation and blood infection if introduced elsewhere in the body
Ethos	The fundamental character or spirit of a culture; the underlying sentiment that informs the beliefs, customs, or practices of a group or society.
Indicator	A characteristic of the environment (biological and physical) that, when measured, quantifies the magnitude of stress, habitat characteristics, degree of exposure to the stressor or degree of ecological response to the exposure (Cairns et al. 1993).
Institutions	"Institutions of knowledge" are the rules of the knowledge-making game. These rules and practices are different for each indigenous group (Berkes 2009).
Socio-cultural values	A set of beliefs, customs, practices and behaviour that exists within a population.
Values	The standards that define how a person/he/she should behave in life, what actions or events merit approval or disapproval, or institutions of knowledge.

`Ōlelo Maoli, Hawai`i and Colloquial Language

Multiple sources were referred to for this glossary (Andrews 1865, Titcomb et al. 1978, Pukui and Elbert 1986, Beamer 2005, Ulukau 2016).

Akua and `aumākua	Man/environmental ancestor/guardian/god/deity with continuing influence – although often translated as 'god' and now also used for the Christian God, this is a misconception of the real meaning. They are regarded as ancestors with influence over particular domains and related to man.
`Āina	Land and sea; lit. that which feeds
Ali`i	Higher chief, ruling chief
Ahupua`a	A geographical unit; and can run from inland to sea, or across the island - coast to coast
A`ole	A universal negative – e.g. 'nothing'.
`Auwai	Water ditch system
Hamau ka leo	Hamau: Silence; hush; be still. Ka leo: your voice.
Holoholo	To go for a walk, ride, or sail; to go out for pleasure, stroll, promenade. This is the ethic used when going fishing to not impose on the fishery.
He`e	Octopus, commonly called squid in Hawai`i
Hula	Traditional dance/performance/action song of Kānaka Maoli.
`ili	A geographical land unit that is smaller than moku and ahupua`a.
Kalo	Also, known as taro, *Colocasia esculenta*.
Kanaka/Kānaka	Kanaka is Person, Kānaka is People
Kānaka Maoli	The Indigenous People of Hawai`i
Kānaka Maoli principles	A philosophical doctrine, incorporating the knowledge, skills, attitutes and values of Kanaka Maoli society.
Kāne	The ancestory/deity/god of the forest realm and man.
Kapu	Prohibited, closed, restricted.
Ko`olau	Windward.
Konohiki	Resource manager for an ali`i of an ahupua`a.
Kupe`e	Gastropod, snail.
Kūpuna	Elder, ancestor
Lawai`a	Fisherman, fisherwoman.
Lobster	Ula/Crayfish are called lobster in Hawai`i.
Lo`i kalo	Terraced taro ponds/wetland system.
Limu	Algae, seaweed.
Loko	Loko is the term for any type of pond and refers to a pool, pond, lake, or other enclosed body of water. Loko included loko kuapā, loko pu`uone, loko wai, loko

	i`a kalo/loko lo`i kalo, and loko `ume`iki.
Loko i`a	Traditional Hawaiian fishpond.
Mākāhā	Sluice gate on loko i`a.
Makahiki	Annual procession of the god Lono where a tribute was collected.
Mauka	Direction: towards the mountains/inland.
Makai	Direction: towards the sea/coast/ocean.
Mauka Makai	Stretching from the mountain/inland to the sea.
Makai Makai	Stretching from one coastline to the other coastline.
Mālama	To take care of, tend, protect or preserve – e.g. mālama `āina: to care for the environment/land.
Maoli	Native, Indigenous, aborigine, true, real, actual, e.g. Kanaka Maoli: Native Hawaiian; `ōlelo maoli: Hawaiian language.
Mele	Songs.
Mo`i li`i	Juvenile mo`i.
Moku	A geographical unit; it marks a district or regional boundary.
Muliwai	Estuary, stream mouth.
`Ōlelo	Language, speech, word, quotation, statement, utterance, term, tidings; to speak, say, state, talk, mention, quote, converse, tell, oral, verbatim, verbal
Pono	Harmony.
Pule	Pray, incantation.
Va`a	Waka – canoe.

Te Reo Māori, Māori Language

Definitions were sourced from multiple dictionaries and articles.

Atua	Ancestory with continuing influence, god, deity – although often translated as 'god' and now also used for the Christian God, this is a misconception of the real meaning. They are regarded as ancestors with influence over particular domains and related to man.
Hāngi	Food cooked within an earth oven.
Hapū	Kinship group, clan, tribe, sub-tribe, extended family – often refers to a sub-tribal/extended family kinship group, that consists of extend family who descend from a common ancestor.
Iwi	Extended kinship group, tribe, nation, people, nationality – often refers to a large group of people descended from a common ancestor and associated with a district territory.
Kāinga	Home, residence, village, settlement.
Kaitiaki, also see tangata tiaki	The contemporary definition is utilised in this research in regards to fisheries: The custodian, guardian, keeper, steward of customary fisheries designated by Tangata whenua.
Kaitiakitanga	The intergenerational exercise of customary custodianship, in a manner that incorporates spiritual matters, by those who hold mana whenua/moana status for a particular area or resource.
Kanakana	Lamprey, *Geotria australis*.
Kanohi-ki-te-kanohi	Face-to-face.
Kaumātua	Elders, ancestors.
Kaupapa Māori	Māori approach, Māori topic, Māori customary practice, Māori institution, Māori agenda, Māori principles, Māori ideology – a philosophical doctrine, incorporating the knowledge, skills, attitutes and values of Māori society.
Koha	A token/gesture of good will and gratitude.
Ki uta ki tai	From inland to the coastline or sea.
Kōrero o mua	Traditional narrative/story.
Mahinga kai	Places at which food (and other commodities) were extracted or produced; and it also signified food items obtained at those places, the methods by which food was secured, cooked or prepared for eating, or preserved for later use or for gift exchange
Mana	Pretige, authority, status.
Mana whenua	Refers to the local tribe/sub-tribal group who hold mana and have 'demonstrated authority' over land or territory in an area, authority which is derived through whakapapa links to that area.

Māori	Indigenous People of Aotearoa, Lit. original, normal, ordinary
Maramataka	Māori lunar calendar – a planting and fishing monthly almanac.
Mātaitai reserves	Customary fishing reserves under Treaty of Waitangi fisheries settlement
Māunga	Mountain.
Mokopuna	Grandchildren.
Ngāi Tahu	The indigenous tribe who hold mana or authority in Te Waipounamu/South Island of New Zealand, excluding the top of the South Island.
Papatipu Rūnanga/Rūnaka	The Papatipu Rūnanga is the customary/tribal assembly, usually at local hapū level.
Rāhui	A closure on harvesting and/or activities within a site, due to, but not limited to, health and environmental disturbances (i.e. the earthquake and its associated sewer impacts), any incidents from being in the sea, or marine habitat restoration purposes.
Tamariki	Children.
Tangata, Tāngata	Person, people.
Tangata tiaki, also see Kaitiaki	The contemporary definition is utilised in this research in regards to fisheries: The custodian, guardian, keeper, steward of customary fisheries designated by Tangata whenua.
Tangata whenua	Indigenous People of Aotearoa New Zealand, Lit. people of the land.
Tūrangawaewae	Domicile, place where one has rights of residence and belonging though kinship and whakapapa. Lit. 'place of standing'.
Waiata	Songs.
Waiata a-ringa	Tranditional action songs/dance/performance of Māori.
Waka ama	Outrigger canoe.
Wakawaka	Traditional Ngāi Tahu management system that ensured the widest possible range of tribal members shared in a resource.
Whakapapa	Genealogy or relationships. Whakapapa is the central principle that ordered the universe (Salmond 1991); a taxonomic and ecosystems map (Roberts 2013).
Whakawhanaungatanga	Process of establishing relationships, relating well to others.

Chapter 1 General Introduction

1.1. Estuarine systems

Estuaries are socially, culturally and ecologically important environments of the coastal zone. These are transitional systems where freshwater and seawater mix, creating one of the most productive ecological habitats , as such support a diversity of flora and fauna. Estuarine habitats include spawning and nursery grounds for many migrating fish and birds, vital feeding and resting areas for many animals and habitats for sedentary species such as shellfish (McDowall 1976, Correll 1978, Little 2000). They are valuable coastal settlements, with 71% of the world's coastal people living within 50 km of an estuary (Janetos et al. 2005), providing well-being, sustenance and economic value.

Kānaka Maoli and Tangata whenua developed a complex society inseparably linked with the environment. Traditional resources were shaped by socio-political land-and-sea systems (Costa-Pierce 1987, Tau et al. 1992, Beamer 2005). In Hawai`i, muliwai/estuaries were zoned by Kanaka Maoli with kaha wai/freshwater ecosystems and streams of the land-and-sea systems, (Mueller-Dombois 2007) and supported unique aquaculture systems (Apple and Kikuchi 1975). Within Waitaha (Canterbury, New Zealand), estuaries were part of extensive Ngāi Tahu mahinga kai networks (Tau et al. 1992, Memon et al. 2003). The important connection of freshwater systems to estuarine systems is evident within traditional whakapapa (Figure 5.1), and the traditional hapū connection from inland to coastal areas (Best 1929).

Estuaries rank among the most anthropogenically impacted aquatic ecosystems on earth (Kennish 2016), which is detrimental to the range of important ecosystem services they provide: raw materials and food, coastal protection, support for aquatic life (e.g. fishery nurseries) and nutrient cycling (i.e., waste dilution and removal) (Costanza et al. 1998, O'Higgins et al. 2010). As a consequence of degradation, New Zealand estuaries have experienced loss and depletion of aquatic flora and fauna, including bivalve organisms (Grant and Hay 2003, Cummings et al. 2007) and were classified vulnerable due to moderate declines in ecological function (Holdaway et al. 2012). Although the Hawaiian Islands are the most isolated archipelago in the world, development and Westernisation has seen an extreme decline in estuaries and wetlands, and the greatest number of known extinctions for any fauna and flora (Nelson et al. 2007).

The degradation of estuaries and estuarine bivalves affects socio-ecological relationships, wellbeing and knowledge systems. Estuarine and coastal system provide recreational, cultural, and aesthetic services (Ghermandi et al. 2009, Barbier et al. 2011). In particular, the services that accompany fisheries, including cultural services, are degraded as a result of a decline in the quantity of fish

(Millennium Ecosystem Assessment 2005). Without intact systems and environmental resources, Indigenous Peoples cannot nurture these socio-ecological relationships (Simpson 2005, McCarthy et al. 2014). Effective management of estuaries requires the identification of anthropogenic impacts on socio-cultural values and co-management inclusive of Indigenous People and local communities.

Bivalves typically comprise one of the dominant groups in many infaunal communities (Dame, 1996). They are part of the food web, influence water quality and facilitate the establishment of complex communities (Coen and Luckenbach 2000, Bolam et al. 2002, Dame 2011, Jones 2011). The decline of shellfish health and populations has been linked with anthropogenic modifications, sedimentation, and contaminants (De Luca-Abbott et al. 2000, Norkko et al. 2006). For instance, low level stressors can affect growth and reproduction, and over time may affect population and ultimately community structure (Stewart 2006). Shellfish at O`ahu were listed as one of the top seven United States (U.S.) most heavily contaminated areas(Ahmed 1991). Contamination is also of concern in New Zealand, particularly where the risk of shellfish consumption may affect local iwi and other community residents (Adkins and Marsden 2009, Fisher and Vallance 2010, Phillips et al. 2011, King and Lake 2013). The impacts of anthropogenic stressors to estuarine bivalves communities can threaten ecosystem functioning (Sandwell et al. 2009, Dame 2011). Ultimately, estuarine fishery organisms and their wider habitat could be utilised as socio-cultural indicators for a range of management practices and value systems.

The objective of this thesis was to evaluate the socio-cultural and ecological indicators of estuarine shellfish and habitat condition in Hawai`i and Aotearoa New Zealand. In both Aotearoa New Zealand and Hawai`i the social, cultural and ecological values of coastal waters and environment are protected by legislation (Section 1.2.1) but these values are rarely utilised together in decision making. The Hawai`i and Ngai Tahu management philosophy, 'mauka makai' and 'ki uta ki tai', respectively ('from mountain/inland to the sea'), forms the overarching principle of this study. To explore multiple indicators and management the following were assessed: catchment land development intensity (LDI) using Geographical Information Systems (GIS), shellfish health (population structure, size, condition index) contamination of shellfish and habitats (*E. coli* and a suite of trace metals,), abiotic characteristics (physico-chemical variables and grain size composition), and quantitative and qualitative interviews (ecological knowledge, values and practices).

1.2. Background

1.2.1. Legislation setting

The protection of social, cultural, and ecological values, and inclusion of Tangata whenua values within ecological resource management, have long existed in the legislated setting of Article II of the

Treaty of Waitangi (1840) and the Resource Management Act (1991) within Aotearoa New Zealand. However, engagement, participation, partnership and co-management between Tangata whenua and Government is required (Wright et al. 1995, Harmsworth 2005, Tipa and Welch 2006).

In the United States of America, the Clean Water Act (CWA 1972), the Coastal Zone Management Act (CZMA 1972), and the Aha Moku Act (2012) were part of several significant laws passed by the U.S. Congress, the former between 1972 and 1874, the latter specifically within Hawai`i in 2010, to protect the social, cultural and ecological values of the environment.

Resource Management Act, Aotearoa New Zealand

In the Resource Management Act (1991), sustainable management means managing the use, development and protection of natural and physical resources in a way, or at a rate that enables people and communities to provide for their social, economic, and cultural well-being and for their health and safety while sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and

(a) safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and
(b) avoiding, remedying or mitigating any adverse effects of activities on the environment (Resource Management Act 1991).

Additionally, within the third schedule, waters may be managed for cultural purposes and may be classified for such purposes where cultural or spiritual values are specified for that area (Resource Management Act 1991). Such values, including burial sites and traditional food gathering areas, are of particular significance to Māori, but other groups may also consider an area to having cultural or spiritual value (Resource Management Act 1991).

Coastal Legislation, the United States

The Federal Water Pollution Control Act, or commonly called the Clean Water Act (CWA), was originally enacted in 1948 to protect the nation's waters, and was revised in 1972 with the national objective "*to restore and maintain the chemical, physical, and biological integrity of the Nation's waters*" (CWA 1972). Within this objective was the interim provision, to achieve '*water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water*' (CWA 1972). The Act also provides citizens with a strong role to play in protecting and restoring waters.

Among the requirements within the Coastal Zone Management Act (1972), two of these declared by Congress were: (1) to preserve, protect, develop, and where possible, to restore or enhance, the resources of the Nation's coastal zone for this and succeeding generations; (2) to encourage and assist the states to exercise effectively their responsibilities in the coastal zone through the development and implementation of management programs to achieve wise use of the land and water resources of the coastal zone, giving full consideration to ecological, cultural, historic, and aesthetic values as well as the needs for compatible economic development (CZMA 1972).

The CZM Act of 1972 was modified by the U.S. Congress in 1990, with enactment of the Coastal Zone Act Reauthorisation Amendments (CZARA) to include a new section entitled "Protecting Coastal Water" (Section 6217) (CZARA 1990). This required states with CZM programs to develop and implement coastal nonpoint pollution control programs to be approved by the federal National Oceanic and Atmospheric Administration (NOAA) and the United States Environmental Protection Agency (U.S. EPA). The Hawaiian coastal nonpoint pollution control program management plan seeks to meet the program components required under Section 6217 of the CZARA.

`Aha Moku, Hawai`i

`Aha Moku, literally translates as the 'Council of Districts'and pertains to the indigenous resource management practices of Native Hawaiians. The purpose of the `Aha Moku Act 288 in the Hawaii Legislative Session Laws 2012 was to formally recognise the `Aha Moku System and establish the Aha Moku Advisory Committee (AMAC) within the Department of Land and Natural Resources (DLNR). The Aha Moku System was restored for 43 moku in the State of Hawai`i through the combined efforts of kupuna and Native Hawaiian resource practitioners and the Aha Kiole Advisory Committee.

The legislature (Act 288 2012) recognised that: "*Over the past two hundred years, Hawaii has experienced extensive changes. These changes include the deterioration of the Hawaiian culture, language, values, which have in part resulted in the over-development of the coastline, alteration of freshwater streams, destruction of life-giving watersheds, and decimation of the coral reef, and the decline of endemic marine and terrestrial species. Native Hawaiian culture has knowledge that has been passed on for generations and is still practiced for the purpose of perpetuating traditional protocols, caring for and protecting the environment, and strengthening cultural and spiritual connections. It is through the Aha Moku Councils that Native Hawaiians protected their environment and sustain the abundance of resources that they depended on for thousands of years".*

1.2.2. Socio-cultural and ecological indices

Socio-cultural indices

The worldview embraced by traditional knowledge holders typically emphasises the symbiotic nature of the relationship between humans and the natural world (ICSU 2002). Rather than opposing man and nature as in Western thought, traditional holders tend to view people, animals, plants and other elements of the universe as interconnected by a network of social relations and obligations (ICSU 2002). "*Awareness of indigenous perspectives, especially values, is critical today, as diversity of culture, language, ethnicity, and national origin continues to be the focus of reclaimed identity and sovereignty for indigenous peoples*" (Kawakami et al. 2008). Both Kanaka Maoli and Māori/Tangata whenua are reclaiming knowledge systems towards better addressing cultural-based environmental management.

Kanaka Maoli and Tangata whenua, both Indigenous Pacific Peoples, trace their origins back to the environment. It is the duty of Hawaiians to mālama `āina and as a result of this proper behaviour, the `āina will mālama Hawaiians (Kame'eleihiwa 1992). Furthermore, it is done with the notion of a familial relationship with `āina (Kame'eleihiwa 1992). Similarly, whakapapa encapsulated and emphasised the familial connection of Tangata whenua with the environment (Tomlins-Jahnke and Forster 2015). Tangata whenua are bound by whakapapa and responsibilities are conferred upon descendants by past generations to also determine reponsibilities for future generations (Harmsworth 2005). It is the shaping of ecology with culture and vice versa, that has created the environmental ethos of Kanaka Maoli and Tangata whenua.

A fundamental problem is the understanding of 'cultural values' and their tangible, intangible and qualitative nature (Jackson 2005). The Cultural Health Index (CHI) was developed in Aotearoa, New Zealand, as a tool based on cultural values and knowledge that provides a means by which iwi can communicate with water managers within the resource management process (Tipa and Teirney 2003). Additionally, the CHI was found to be significantly correlated with scientific measures of stream health, and to encapsulate the relationship between land development and stream health (Townsend et al. 2004).

More traditional forms of knowledge transition were in the form of narrative, also called pūrakau/stories, mythology, talk story, or have taken the form of waiata/mele (songs) and waiata a ringa/hula (action song/dance/performance) in Aotearoa and Hawai`i. This is one of the key ways knowledge was sustained and protected within Indigenous communities (Lee 2009). These narratives contain detailed explanations of tribal events and of environmental ethics that may guide future management practices (Handy et al. 1972, Patterson 1994, Lee 2009, Berkes 2012). Narratives have largely been unwritten (Patterson 1994) and this requires a context-driven approach. Further, Indigenous or traditional ecological knowledge should be recognised as process (Berkes 2009, Moller et al. 2009a) that adapts over time.

Traditional knowledge and management systems have been developed through millennia to enable many societies to use the environment in a way that maintains the integrity of local ecosystems (Berkes 1989). However, the social, cultural, and ecological values of coastal waters relating to the environment are rarely utilised together in decision making because; (a) they are difficult to combine or integrate due to differing worldviews and methods of inquiry; (b) socio-cultural-based methodologies have only recently been developed or included (Harmsworth and Tipa 2006): and (c) Indigenous-based views and knowledge are rarely accepted as adequate knowledge systems towards decision-making (Jackson 2005). In an Indigenous worldview, the dichotomy between the value sets of culture and nature, is not observed by Indigenous People, who maintain a strong interest in both domains through their socio-ecological relations (Jackson 2005). The ecological knowledge systems of Indigenous Peoples have long supported sustainable management of natural resources (Ulluwishewa et al. 2008).

An indigene-based approach, of cultural-ecological knowledge is vital in representing Indigenous Peoples' perspectives. It is argued that successful natural resource management and practices increasingly depend on pluralistic action and co-management partnerships between conservation management and non-governmental groups such as Indigenous People (Moller et al. 2004). The first challenge is to recognise that within an indigenous context, a different suite of species and indicators may be considered important when compared to those valued by other stakeholders (Finn and Jackson 2011). Another fundamental problem is the understanding of 'cultural values' and their tangible, intangible and qualitative nature (Jackson 2005). Values, traditions, customs and beliefs all contribute to cultural distinctiveness (Groenfeldt 2003). As used here, culture refers to the system of values, beliefs, knowledge and connections to a place that social groups make use of in experiencing and interpretating the world in mutually meaningful ways.

There is a critical need to ensure non-use values are more visible and given greater weight in policy analysis and management decisions (Jackson 2005). An evaluation of freshwater ecosystem services in the United States warns against omitting significant 'non-use' values and thus overestimating the role of 'use' values (Wilson and Carpenter 1999). For example, cultural ecosystem services (ES) are almost entirely unquantified in scenario modelling; therefore, the calculated model results do not fully capture the losses of these services that occur in the scenarios (Rodríguez et al. 2006). The current ES framework requires redesigning to better address and native cultural values (Chan et al. 2012), this also applies to the cultural values and cultural services as defined by Indigenous Māori (Harmsworth and Awatere 2013).

The knowledge held by local and Indigenous People, is a source of information, especially for marine conservation and fisheries management purposes (Berkes et al. 2000a, Huntington 2000). Traditional

Ecological Knowledge (TEK) in particular can help identify different habitat areas (e.g., spawning areas and juvenile habitats), and fish species, including their distributions and interactions (Drew 2005). Habitat-faunal association mapping can demonstrate the value of ecosystem services of estuarine fisheries (O'Higgins et al. 2010). Additionally, geographical information systems (GIS) models have incorporated TEK for fisheries, marine, and conservation management (Calamia 1999, Drew 2005, Close and Brent Hall 2006). Utilising TEK lends itself towards integration with modern day ecosystem management and restoration practices in Hawai`i (Hufana 2014).

Catchment paradigm

Whole system management stems from a traditional-ecological framework of working *with* the environment. A catchment-to-sea or "ridge to reef" paradigm has become a familiar management theme throughout the Pacific (Richmond et al. 2007, USGS 2008). Hawaiian ahupua`a were managed as integrated watershed systems (Costa-Pierce 1987, Jokiel et al. 2010) that run from mauka ki makai (Handy and Pukui 1998). Similarly for Ngāi Tahu, ki uta ki tai reflects their resource management philosophy (Hepburn et al. 2010, Mahaanui Kura Taiao Ltd 2013). The paradigm includes people within the system rather than as observers, a worldview shared by Indigenous People. This philosophy is included within the socio-cultural interviews of the present study as is the quantification of the landscape condition of selected catchments.

Globally, it is evident that estuaries and coastal systems are receptors of surrounding catchments and are influenced by land-sourced nutrients, contaminants and sediments (Kennish 2001, 2002, Bricker et al. 2008, Crain et al. 2009). Human-dominated land uses can affect adjacent ecological communities through direct, secondary and cumulative impacts (Brown and Vivas 2005). Landscape indices have been combined with aquatic metrics to evaluate the cumulative anthropogenic impacts across spatial scales (Cohen et al. 2004, Mack 2006, Greene et al. 2014). The advantange of a Landscape Development Intensity (LDI) index is that it quantifies the effects of human disturbances along a continuous gradient, from 1 to 10; 1 for natural systems and 10 for central business districts (Brown and Vivas 2005). On the Island of O`ahu, Hawai`i the following studies utilised the LDI index with the biological and abiotic metrics of aquatic systems (Jensen 2014, Margriter et al. 2014, Ratana 2014). Margriter et al. (2014) demonstrated that the LDI at larger scales (e.g. watersheds) can, in addition to wetland samples, provide useful indicators of regional stressors (e.g. human land-use impacts upon water quality and overall wetland conditions) for management. At present, the LDI has not been applied within the evaluation of the intertidal estuarine zones in New Zealand or Hawai`i, and there has been no research conducted into associated shellfish indicators or socio-cultural values. Investigating these relationships could inform better 'land to sea' management.

Biological indicators

A biological indicators approach was undertaken in this study. This classical approach involves monitoring a suite of selected stress responses at several levels of biological organisation in order to: (1) assess the effects of sub-lethal stress to the organism; (2) investigate the early cues of stress; and (3) evaluate causal relationships between stress and the effects at the community and ecosystem level (Adams et al. 1989). Bivalve density and population structure can illustrate population stability (Flach 1996, Gam et al. 2010, Genelt-Yanovskiy et al. 2010) and the Condition Index (CI) is a proxy of organism health (Crosby and Gale 1990). It is known that these bivalve metrics are influenced by estuarine condition (Craig 1994, Defeo and de Alava 1995, Carmichael et al. 2004, Gagné et al. 2008), watershed land use (Hale et al. 2004, King et al. 2005), water quality parameters (Craig 1994, Defeo and de Alava 1995, Carmichael et al. 2004, Gagné et al. 2008), and sediment characteristics (Arbuckle and Downing 2002, Herrmann et al. 2009).

Globally, bivalve molluscs have been used as sentinel organisms to assess levels of contamination in estuarine and coastal ecosystems. Bivalve species utilised have included mussels (Gault et al. 1983, Ólafsson 1986), oysters (Phillips and Muttarasin 1985, NOAA 1989b, Sarkar et al. 1994, Hunter et al. 1995, Love et al. 2010), clams (Dougherty 1988, Luoma et al. 1990, Páez-Osuna et al. 1993a, Usero et al. 1997, Peake et al. 2006, Love et al. 2010, Marsden et al. 2014) and cockles (Phillips and Muttarasin 1985, Szefer et al. 1999). Aquatic invertebrates take up and accumulate trace metals and microbacteria, which have the potential to impair function or cause toxic effects. The total rate of metal uptake into the tissues of a bivalve depends upon its physiology, age, source of uptake (aquatic solution or diet), the metal speciation and concentration in seawater, suspended material and/or associated sediment (Landner and Reuther 2004, Casas et al. 2008, Luoma and Rainbow 2008, Marsden et al. 2014). Metal speciation can also be dependent upon the site-specific seasonal and spatial variations existing in a particular water, sediment or soil system (Landner and Reuther 2004).

In Hawai`i and New Zealand, bivalves have been utilised as indicators of trace metal and microbiological contamination (Hunter et al. 1995, Frew et al. 1997, De Luca-Abbott et al. 2000, Peake et al. 2006, Connell et al. 2012, Marsden et al. 2014). In Hawai`i, the Pacific oyster *Crassostrea gigas* which is utilised as the United States sentinel organism, was evaluated for the first time in Kāne`ohe Bay by Hunter et al. (1995). They found much higher trace metal concentrations in *C. gigas* from Hawai`i than fromthe East and Gulf coasts of the mainland United States (Hunter et al. 1995). The study also indicated site-specific elevated contamination, which increased with catchment urbanisation (Hunter et al. 1995). In New Zealand, the cockle species, *Austrovenus stutchburyi* has been used as a bioindicator of trace metal in estuaries (Peake et al. 2006, Marsden et al. 2014, Stewart et al. 2014). Similar to the above findings in Hawai`i, *A. stutchburyi* tissue trace metal concentrations were location specific (Marsden et al. 2014, Stewart et al. 2014) and elevated near urbanised catchments (Peake et al. 2006, Stewart et al. 2014). A replicate study to Hunter et al. (1995) and an investigation of *C. gigas* population structure has not yet been conducted, nor has an environmental condition investigation of the once-abundant edible clam species (Haws et al. 2014). Conversely, there is an increasing body of knowledge of *A. stutchburyi* contamination; however, the multiple impacts of catchment land-use and land-cover, tissue and sediment contamination exposure and population effects have yet to be determined in Canterbury estuaries. These effects are important to measure as early cues of stress, before they affect higher levels of organisation and ultimately ecological function.

Sediment can act as a sink for metals (Kennish, 1997) and influences metal availability due to changes in estuarine condition (salinity, pH/redox potential) (Forstner et al., 1989; Morillo et al., 2002) or bioturbation or resuspension (Zoumis et al., 2001). Sediment metal concentration can influence how much is accumulated by sediment dwelling clams. For example, the metal content of copper and silver in clams has been shown to follow the sediment metal concentration pattern (Cain & Luoma, 1990).

Inflow from sewage and storm water systems can be elevated during storm events, which can additionally cause sediment resuspension and release of sediment-bound pathogens in receiving environments. Concentrations of *Enterococcus* species and *Escherichia coli* increased with increased particles in suspension following storm events (Fries et al. 2006) and rainfall events (De Luca-Abbott et al. 2000). The bacterial enterococci levels in surficial sediment demonstrated the spatial and temporal patterns of storm water discharge in Whangateau Harbour (De Luca-Abbott et al. 2000).

Human health

Bivalves are a useful tool for monitoring changes within a system. However, the intake of the edible parts of shellfish by humans is an important dietary exposure pathway for contamination including pathogenic bacteria, protozoa, and viruses associated with faecal contamination (Love et al. 2010) as well as organic chemicals, and major and minor metals (Cantillo 1991, Rainbow and Phillips 1993). Bacteria species *E. coli* is an indicator proxy for the presence of faecal contamination and therefore other pathogenic microorganisms that can cause gastrointestinal illness (Dufour and Ballentine 1986). Within this study, *E. coli* is assessed in New Zealand shellfish and compared to food safety standards (ANZECC and ARMCANZ 2000) but has not been investigated in Hawai`i shellfish due to the limitation of laboratory services for this test. The concentrations of inorganic arsenic, cadmium, mercury and lead are of great concern because of their toxicity to human health (U.S.FDA 1993, FSANZ 2015).

1.3. Thesis scope and objectives

The overall objective of this thesis was to evaluate the socio-cultural and ecological indicators of estuarine shellfish and habitat condition using a combined approach of scientific and socio-cultural knowledge to assess estuarine resources and condition in O`ahu Island (Hawai`i) and Waitaha/Canterbury (Aotearoa New Zealand). The Hawai`i and Ngāi Tahu management philosophy, 'mauka makai' and 'ki uta ki tai', respectively ('from mountain to sea'), forms the overarching guidance for this study. Estuarine sites were chosen to represent varying land-uses, fishery management (customary/traditional versus open-sites) and physico-chemical characteristics (e.g. salinity).

Engagement with relevant groups was undertaken prior to beginning research, particularly Kanaka Maoli and Tangata whenua in Hawai'i and Aotearoa New Zealand respectively. Interviews/surveys with a broad range of 'estuarine/beach-goers', long-term residents, and environmental guardians. To explore multiple indicators and management the following were assessed: shellfish (trace metals, *E. coli*, population structure) and habitat (sediment contaminants and grain size), water parameters and weather, land development intensity (LDI using GIS), quantitative and qualitative interview (values and indicators). The thesis is divided into seven chapters as follows.

Chapter 1: Introduction.
Chapter 2: General methodology.
Chapter 3: The socio-cultural indices of shellfisheries in Hawai`i.
Chapter 4: The ecological indices of shellfisheries in Hawai`i.
Chapter 5: The socio-cultural indices of shellfisheries in New Zealand.
Chapter 6: The ecological indices of shellfisheries in New Zealand.
Chapter 7: General discussion.

Chapter 2 General Methodology

2.1. Socio-cultural survey

Recreational Participants (RP) and Local Practitioners and Specialists (LPS) were interviewed to investigate the socio-cultural values of site and catchment, environmental condition, resource abundances and changes, and the management effectiveness of these systems. Recreational Participants consisted of 'beach-goers', fishers, harvesters, who were intercepted at a range of locations around each of the study sites. Kanohi-ki-te-kanohi (face-to-face) questionnaires were selected to assess the socio-culturalsocio-cultural perception of RP. This method was previously utilised in mixed-methodology research of local-based activities (Crawford and Fountain 2010, Fisher and Vallance 2010). The interviews were conducted in person onsite or if preferred later via telephone or email.

Local Practitioners and Specialists (LPS) consisted of local authority members, kaitiaki/local customary authority and stewards, kaumātua/kūpuna, managers, long-term residents, and scientist who had considerable long-term experience with the focus area. Engagement with relevant groups, particularly Kānaka Maoli in Hawai'i and Tangata whenua in New Zealand respectively, were undertaken by meeting kanohi-ki-te-kanohi, as integral to the research process. The LPS were purposely interviewed in a semi-structured style to generate understanding and in depth discussion(Patton 2002). All interviewees were fully briefed as to the purpose of the interviews, and consent was sought. A map of the area provided opportunity to visualise the selected site and note down any relevant GIS information when permitted. Snowball sampling (Goodman 1961) was used to further identify individuals with a direct relationship with the study sites. This method of sampling is when existing interviewees provide future interviewees from among their acquiantances. Following the interview process, the interviews were transcribed, and returned to the participant for further editing or comments before analysis. The actual interview content and participant names will remain confidential.

A copy of the LPS and RP survey forms are provided in Appendix 2.1 and 2.2, respectively. Ethical approval was granted by Institution Review Board of Hawai`i Pacific University under provision of CRF 46.114 (Cooperative Research), and both the Human Ethics Committee and the Māori Research Advisory Group of the University of Canterbury (HEC 2013/158).

2.1.1. Worldview

When conducting indigenous research, an important methodology is to embed the interview process and analysis within their respective cultural worldview. According to Tipa and Teirney (2003), interviews with Tangata whenua are an important and effective way of gathering specialist knowledge of the traditional resource sites. Emphasising local indigenous methodologies such as Kaupapa Māori and Kānaka Maoli principles is vital towards indigenous worldview, language, and validating indigenous knowledge systems (Smith 1997, Smith 1999, Pihama et al. 2002, Kawakami et al. 2008). Important principles and approaches such as whakawhanaungatanga/building relationships, whakapapa/genealogy, utilisation of local language, and koha were included within this research.

Relationships in an indigenous sense can be encompassed within the human relationships with each other, towards the natural environment, and the metaphysical realm. Whakawhanaungatanga was essential to provide time, space, authenticity and reciprocity. As the researcher, I participated in volunteer days, met with local community members, researchers and specialists, and attended public meetings. These were to ground myself in local protocols, language, and "kia pono te mahi pūtaiao – doing science in the right spirit" (Allen et al. 2009). In the Ko`olaupoko District of O`ahu, Hawai`i, engagement and discussions were conducted with Kānaka Maoli, loko i`a managers and groups, and the Ko`olaupoko Hawaiian Civic Club. In Waitaha, Aotearoa (Canterbury, New Zealand), engagement and discussions were conducted with Ngāi Tahu, mātaitai reserve committee, and Papatipu Rūnaka.

2.1.2. Mixed methodology

The interviews were analysed using a mixed-methods approach with an explanatory design (Goodrick and Emmerson 2009). This approach emphasises the quantitative indices and provides further description and depth with qualitative data (Goodrick and Emmerson 2009). The interview questionnaires (Appendix 2.1 and 2.2).

Qualitative analysis

The interviews were transcribed and checked by participants before a final copy was analysed in NVivo™ 11. A grounded 'emergence' theory approach was used to interpret participants' interviews (Glaser 1992), because cultural values can be inclusive of tangible, intangible, and qualitative nature (Jackson 2005). This method is important to incorporate indigenous perspectives within cross-cultural work (e.g. McCarthy et al. 2013). Additionally, ancestral sayings were sourced using literature and narrative to provide further necessary context to those given by participants. Ancestral sayings as a medium of TEK have provided important ecological information, environmental parameters, and informs management (Wehi 2009). This methodology and analysis process further recognises the differences and validity in both science and Traditional Ecological Knowledge or Indigenous Knowledge (including Mātauranga) (Berkes 2009, Moller et al. 2009a).

Quantitative analysis

The quantitative data from interviews were coded into Microsoft Excel™ and analysed using Statistica™ Version 13. The method for scoring data are provided within each of the respective chapters, so are the statistical analysis due to the differences in sample size gathered in Hawai`i to Aotearoa New Zealand. The assumptions of each tests were first checked prior to analyses. The socio-cultural values and indices were compared by selected participant attributes, including group (LPS and RP), cultural affiliation, experience (years), and location (site/area). Due to differences in participant sample size, the statistical tests varied between Chapter 3 and 5. Specific details are provided within the method section of each respective chapter.

The following list provides the focal interview objectives:

1. To identify who visits the area and socio-cultural affiliations
2. Site and Activities: To evaluate the traditional uses, cultural values, and the participants' main activities.
3. Resources: To evaluate what fishery/other resource participants' favoured or targeted, and what were the changes (if any) to the relative abundance(s) over time.
4. Environmental condition: To evaluate the perceived site and catchment condition, and (if any) main changes have occurred over time.
5. Indicators: To investigate if there were main environmental indicators associated to activities and values.
6. Management: To identify current management practices, and if the management was regarded as effective

2.2. Landscape development intensity (LDI) index

The GIS-calculated impervious surface area and Land Development Intensity (LDI) index were used to analyse changes in the land use and land cover over time. In Hawai`i the term 'watershed' is used for the drainage basin area, and in New Zealand the term 'catchment' is used. Both are used in this thesis within their respective chapters due to the naming of GIS layers.

The catchments/watershed, streams, and land use/land cover (LU/LC), associated with shellfish sites were mapped for Kāne`ohe Bay in O`ahu, and four estuaries in Waitaha/Canterbury in New Zealand. These values were calculated to investigate the relationship between catchment and sites.

In O`ahu, the landscape scores were calculated using the 1978 GIS LU/LC map, and the 2005 Coastal Change Analysis Program (C-CAP) data available from the National Oceanic and Atmospheric Administration (NOAA). In addition, historical conventional maps were investigated in relation to major changes listed within interviews. The 1978 and 2005 GIS data layers were provided by State of Hawai`i Office of Planning (OP 2014), and the 1978, 1983, and 1998 conventional maps were provided by the United States Geological Survey (USGS 1943, 1983, 1998).

In Canterbury, the two landscape scores were calculated for the main catchments of the four study estuaries using the 2012 land cover (LRIS 2012). Further GIS data to create the maps were downloaded from multiple Crown Agency databases (LRIS 2012, Canterbury Maps 2015, LINZ 2015).All files were organised into a geodatabase for each watershed in ArcGIS 10.1. The C-CAP raster layer for the island of O`ahu, and Land Cover layer for New Zealand, was converted to a polygon layer. Land use land cover (LU/LC) classifications were assigned for the respective C-CAP/Land Cover data. The classifications were then matched to the LDI coefficients for Hawai`i (Jensen 2014), and New Zealand (this thesis), both of which are given in Appendix 2.3 and 2.4, respectively.

The total area of impervious surface and watershed area were extracted. The percentage of total watershed area covered by each land use was also calculated. This layer was joined to a table with the averaged corresponding LDI coefficients for each land use classification. A two part model created to run multiple LDI calculations (Ratana 2014) was created using the ArcGIS 10.1 model build (Figure 2.1). The first part of the model used the Hawai`i watershed polygon to clip the streams layer and C-CAP/Land Cover polygon file. The clipped polygon file was then dissolved using both the LU/LC classification and the LDI coefficients. A field containing the total area of the watershed was then added manually to the clipped and dissolved C-CAP/Land Cover layer. The second part of the model added and calculated the percent area and LDI score fields using the equation:

$$\mathrm{LDI}_{\mathrm{total}} = \sum \%\mathrm{LU}_{\mathrm{i}} \cdot \mathrm{LDI}_{\mathrm{i}} \quad \text{(Brown and Vivas 2005)}$$

Where $\mathrm{LDI}_{\mathrm{total}}$ = LDI ranking for landscape unit, $\%\mathrm{LU}_{\mathrm{i}}$ = percent of the total area of influence in land use i, $\mathrm{LDI}_{\mathrm{i}}$ = landscape development intensity coefficient for land use i. The LDI score field was summed, and the C-CAP/Land Cover symbolised using a layer file created to match that of the original raster file. In addition to the LDI scores calculated through running the model, both percent and total area of impervious surface were extracted from the clipped and dissolved C-CAP/Land Cover polygon files.

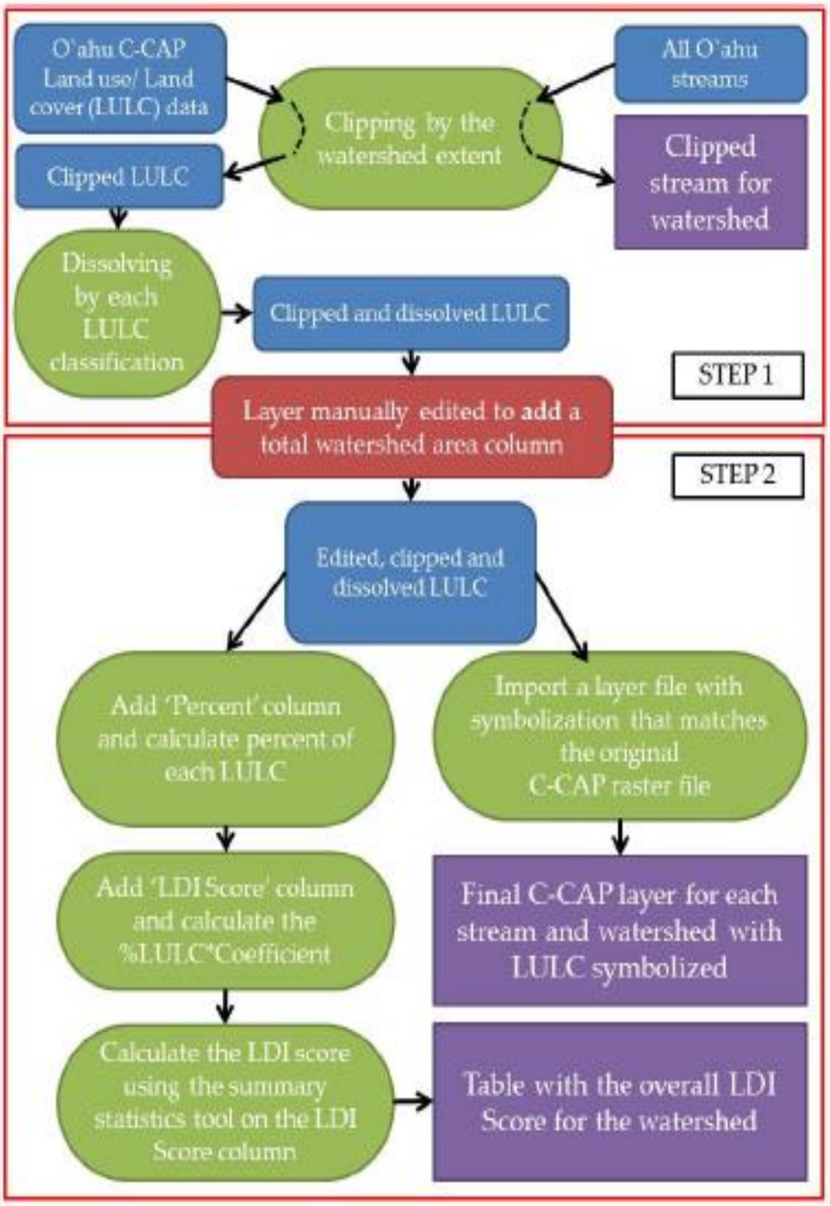

Figure 2.1. The Geographic Information Systems (GIS) model developed by Ratana (2014) to run multiple Landscape Development Intensity index (LDI) calculations. The blue boxes are input and intermediary output data, purple are final output layers of tables, green are model run processes and red are manual run processes.

2.3. Ecological evaluation

A suite of commonly used benthic indicators were chosen to assess the range of environmetnal characteristis within a fine-scale approach (Roberston et al 2002). The ecological variables included the evaluation of shellfish population structure, shellfish condition index, sediment composition, and the contaminant levels of shellfish and sediment. Specific sampling design methods are given in the respective chapters.

Shellfish condition index

The biological measurements and gravimetric Condition Index (CI gravi) were measured for *Crassostrea gigas* in O`ahu, *Austrovenus stutchburyi* and *Paphies australis*, in Waitaha Canterbury. Either volumetric or gravimetric CI methods can be utilised to ascertain nutritive status of bivalves or determine whether the animals are stressed (Crosby and Gale 1990). The bivalve samples were washed clean of any extraneous material and lightly patted dry. The shell length, width, and height were measured using callipers to the nearest 1 mm. The whole live weight (wet soft tissue plus shell), drained and shell weight were weighed to the nearest 1g before removing the tissue with a stainless-steel knife rinsed with clean water between each shellfish sample. Wearing latex gloves, the CI gravi tissue samples were placed into pre-weighed folded foil and placed into the oven for 72hr at 65℃. Following this, the dry tissue and shell samples were re-weighed. . These measurements were used to calculate the CI gravi using the equation:

$$\text{CI gravi} = \frac{\text{dry soft tissue wt (g) x 1000}}{\text{internal shell cavity capacity (g)}}$$

The shell cavity capacity of a bivalve was determined by subtracting dry shell weight (g), in air, from the total whole live weight (g), in air, of a cleaned animal (Crosby and Gale 1990).

Sediment composition

Each wet sediment sample was mixed well using an acid-washed plastic knife before being subsampled for grain size and trace metal analysis. The grain size samples were placed into pre-weighed crucibles. The percent pore water (PW) and total volatile solid (TVS) content were determined from oven dried (72 hr at 65˚C) and ashed (6.5 hr at 450˚C) processing respectively. The ashed sediments were classified to grain size across a stack of sieves of 2 mm, 1 mm, 500 µm, 250 µm, 125 µm, 63 µm, and <63 µm. The Wentworth Scale was used to classify sediment by grain size (Wentworth 1922).

2.4. Contaminant analysis

The trace metal analysis was conducted within the Chemistry Department at the University of Canterbury. The Canterbury tissue and sediment *Escherichia coli* samples were submitted to Hill Laboratories for analysis. The trace metal recoveries of the Certified Reference Material (CRM), limit of detection, and percentage difference between duplicate samples are provided in Appendix 2.5. Given both the shellfish tissue and sediment mercury recoveries were highly variable and problematic they were excluded from data analysis. The trace metal methodology is as follows.

2.4.1. Shellfish tissue

The bivalve samples were washed clean of any extraneous material and lightly patted dry. The shell length, width, and height were measured using callipers to the nearest 1 mm. The whole wet weight (soft tissue plus shell), and drained weight were weighed to the nearest 1g before removing the tissue. The trace metal tissue samples were carefully placed into pre-weighed acid-washed vials using a stainless-steel knife rinsed with 70% ethanol between each shellfish sample. The wet weight, dry weight, and shell weight were recorded before and after freeze-drying. These measurements were used to calculate contaminant concentration.

The shellfish tissue sample, along with the duplicates, blanks, and a mussel tissue Standard Reference Material (CRM 2796 National Institute of Science and Technology, USA – NIST), were digested in pure concentrated nitric acid (HNO_3) and hydrochloric acid (HCl) and left to stand overnight. The acid and water volumes are presented in Table 2.1, as they differed by weight (soft tissue dry weight g). The shellfish were heated to 85˚C and refluxed for 60 minutes and left standing to cool down. The digested samples, duplicates, blanks, and CRM sample, were made up to a known volume with ultra-pure water (Table 2.1) and left to stand overnight.

Table 2.1. The pure concentrated nitric acid (HNO_3), hydrochloric acid(HCl), and ultra-pure water volume (ml) used within the digestion procedure for each sample (grouped by weight (g)).

Soft tissue dry weight (g)	HNO_3 (ml)	HCl (ml)	Water (ml)
≤0.25	1	0.25	10
≥0.26-0.40	2	0.50	20
≥ 0.5-0.90	2	0.50	40
≥ 1.0	4	1.00	50

Two different acids were used within the final dilution methodology for O`ahu and Canterbury shellfish. Since the first was oven-dried in O`ahu to send to Canterbury it could not be assessed for Hg concentrations. In Canterbury, these samples were freeze dried before digestion. A 1 ml sample from each O`ahu digestion sample was diluted by adding 4 ml of 2% HNO_3, mixed well, and analysed by inductively-coupled plasma mass spectroscopy (ICP-MS) for As, Cd, Cr, Cu, Co, Ni, Mn, Pb, and Zn. For the Canterbury shellfish, a 1 ml sample was diluted by adding to 4 ml of 2% HNO_3/0.5% HCl/0.1% L-cysteine, mixed well, and analysed by ICP-MS for the same metals above and Hg. The trace metal recoveries of reference material are provided in Appendix 2.5. Since the Hg reference recovery was highly variable and poor (DORM-4: 28.74±22.68 and NIST 2796: 62.20±18.58) it was excluded from further analysis. By multiplying the dry weight metal concentrations by the wet weight/dry weight factor, the wet weight trace metal concentrations for each individual sample were calculated. This was to allow comparison with the human consumption guidance level.

2.4.2. Sediment

Oven-dried sediment samples were sieved to remove particle sizes >2 mm. One gram of sediment was accurately weighed into acid-washed polycarbonate tubes for digestion. The sample, along with the duplicates, blanks, and the marine sediment Standard Reference Material (CRM 2702 National Institute of Science and Technology, USA) were digested in 4 ml nitric acid ($50\%\ HNO_3$) and 10 ml hydrochloric acid ($20\%\ HCl$) and left to stand overnight. The sediment samples were heated to 85°C and refluxed for 60 minutes before left to stand to cool down. The digested samples, duplicates, blanks, and CRM sample, were made up to a known volume with ultra-pure water and left to stand overnight.

A 0.5 ml sample from each O`ahu digestion sample was added to 10 ml of 2% HNO_3, mixed well, and analysed by inductively-coupled plasma mass spectroscopy (ICP-MS) for As, Cd, Cr, Cu, Co, Ni, Mn, Pb, and Zn. For the Canterbury ssamples, a 0.5 ml of sample was added to 10 ml of Aqua-regia solution, mixed well, and analysed by ICP-MS for the same metals plus Hg.

2.4.3. Metal Pollution Index

The Metal Pollution Index (MPI) was calculated to represent an integrated response to trace metal exposure. The MPI was obtained using the equation:

$$\mathrm{MPI} = (\mathrm{Cf}_1 \times \mathrm{Cf}_2 \ldots \mathrm{Cf}_\mathrm{n})^{1/\mathrm{n}}$$

where Cf_i= concentration for the metal *i* in the sample (Usero et al. 1996). The MPI was calculated with eight trace metals (As, Cd, Co, Cr, Mn, Ni, Pb, and Zn) in sediment and shellfish. This same calculation was used to assess the exposure of the New Zealand littleneck clam (*A. stutchburyi*) and sediment in Canterbury (Marsden et al. 2014).

2.5. Statistical analysis

Normality

The abiotic data (water readings and sediment composition), population biological data (shellfish density (per m^2), CI, shell length (mm)), and trace metal concentration ($\mu g\ g^{-1}$ dry weight) were checked for normality using the Kolmogorov-Smirnov test (n>50) or Shapiro-Wilks test (n<50) in Statistica™ Version 13. All statistical tests were conducted with a significance level of $\alpha<0.05$.

Trace metal comparisons

Before any comparison between tissue trace metal concentrations ($\mu g\ g^{-1}$ dry weight) across sites, it is necessary to check whether there is any effect of shellfish size on accumulated concentration that might compromise any comparisons (Peake et al. 2006). In such cases, it is usual to check for correlations between the soft tissue dry weight and accumulated metal concentration (Luoma and Rainbow 2008). Given that the soft tissue dry weight is variable, shell length can be used as an indicator for shellfish size and correlations calculated between the shell length and the accumulated metal concentration (Marsden et al. 2014). Separate slopes rather than ANCOVA was used to compare trace metal data where significant interactions with size were found.

Correlation analysis and correction procedure

Correlation analyses were used to evaluate the relationship(s) between the land-use development indices (LDI, impervious surface), the contaminant index (MPI), CI gravi, sediment grain size, and environmental variables (temperature, dissolved oxygen, salinity, and pH).

A problem with multiple variable correlations is that there could be a high number of false discovery rates (FDR) (McDonald 2009). This is the proportion of significant results that are actually false-positive inferences by a group, or family, of tests (Cao and Zhang 2014). The Bonferroni is most commonly used for relatively smaller tests (McDonald 2009). The Hochberg sequential test procedure, like the Bonferroni, controls for the family wise error rate (FWER) (Hochberg 1988, McBride 2005, Cao and Zhang 2014). This test improves the Bonferroni statistical power (Verhoeven et al. 2005, Pike 2011, Cao and Zhang 2014). In ecological studies, there is a preference to control the proportion of significant results that are in fact type I errors (‘false discoveries’), instead of controlling the chance of making even a single type I error (García 2003, García 2004). Whereas, FWER control offers limited opportunity to strike a sensible compromise between type I and type II errors (Verhoeven et al. 2005). The Benjamini-Hochberg procedure was developed (Benjamini and Hochberg 1995) and is used in ecological studies with a large number of tests to control for FDR (Benjamini and Hochberg 1995, Waite and Campbell 2006, Pike 2011). FDR control can result in fewer type II errors than controlling the FWER (Verhoeven et al. 2005).

The Benjamini-Hochberg procedure, $P_i < \frac{i}{m}q$,was used in this study to control for FDR (Benjamini and Hochberg 1995), where P_i is the ordered *p*-values, *i* is the rank, *m* is the total number of variables, and q is the chosen false discovery rate. The largest p-value that has $P_i < \frac{i}{m}q$ is significant, and all p-values smaller than it are also significant. This procedure has been used by other researchers to correct for the multiplicity of tests (Stark and Fowles 2006, Whitney et al. 2010) following a non-parametric test. Both correction procedures, Bonferroni and the Benjamini-Hochberg procedure, can be used with the non-parametric multiple correlation analysis (McBride 2005, McDonald 2009). An FDR of 20% is considered a conservative measure, however it depends on the number and expense of running such tests (McDonald 2009). An FDR of 5% was used to test with either 60 tests (60 river sites), and 56 tests (28 scientific families, 28 genera), respectively (Stark and Fowles 2006, Whitney et al. 2010). The FDR for each correlation test is provided within the respective results tables of each chapter.

Chapter 3 The socio-cultural values of shellfisheries in Hawai`i

3.1. Introduction

Kanaka Maoli developed a complex society that was inseparably linked with the environment. Traditional resources were shaped by socio-political land to sea divisions, including ahupua`a and moku (Figure 3.1), that were established by different ali`i, and managed within the wider Konohiki system (Costa-Pierce 1987, Beamer 2005). Ahupua`a were highly integrated and diversified agriculture-aquaculture systems (Figure 3.2) (Costa-Pierce 1987, Berkes et al. 1998). These geographical units may extend from mauka makai:'stretching from inland/mountain to the sea/coastline' (Handy and Pukui 1998), or makai makai: 'stretching from one coastline to the other coastline' (Beamer 2005), and included the coastal fisheries zone (Beamer 2005, Gon 2014). Using archaeological modelling and traditional knowledge, Gon (2014) mapped the pre-historic moku and ahupua`a, and depicts the 1920 fishery within the seaward extension of the ahupua`a units (Figure 3.1). Due to the importance of waterways integrity from land-to-sea, muliwai/estuaries were zoned together with kaha wai/freshwater ecosystems (Mueller-Dombois 2007), and these supported unique aquaculture systems (Apple and Kikuchi 1975). Therefore, integrated catchment management was in practice for many centuries in the traditional Hawaiian society (Jokiel et al. 2010).

Over the past two centuries the current Western system of management has gradually replaced the traditional Hawaiian system (Smith and Pai 1992, Berkes et al. 1998, Jokiel et al. 2010), with resource development and management practices that have treated the environment as discrete boxes of 'resources' (Berkes et al. 2000b). The reorganisation of ahupua`a system marked the beginning of the decline of Hawaiian ecosystems; there was no longer a traditional management system of responsibility for the conservation of land and water resources from mauka makai (Smith and Pai 1992). The current study area is Kāne`ohe Bay in O`ahu, which is the largest estuarine embayment in the Hawaiian Islands (Figure 3.3), and is also one of the most anthropogenically impacted locations in Hawai`i.

Kāne`ohe Bay was historically known as a bread-basket for O`ahu (Kelly 1975), with its extensive productive kalo (taro: *Colocasia esculenta*), loko i`a (traditional Hawaiian fishpond), agriculture, and natural resources (Handy et al 1972). Loko i`a systems were unique to Hawai`i culturing fish, crustaceans, shellfish, and seaweed (Apple and Kikuchi 1975). This bay has had considerable changes in use and its surrounding watersheds, becoming rural/agricultural in the north and urbanised in the south sector of Kāne`ohe Bay (Devaney et al. 1982, Hunter and Evans 1995).

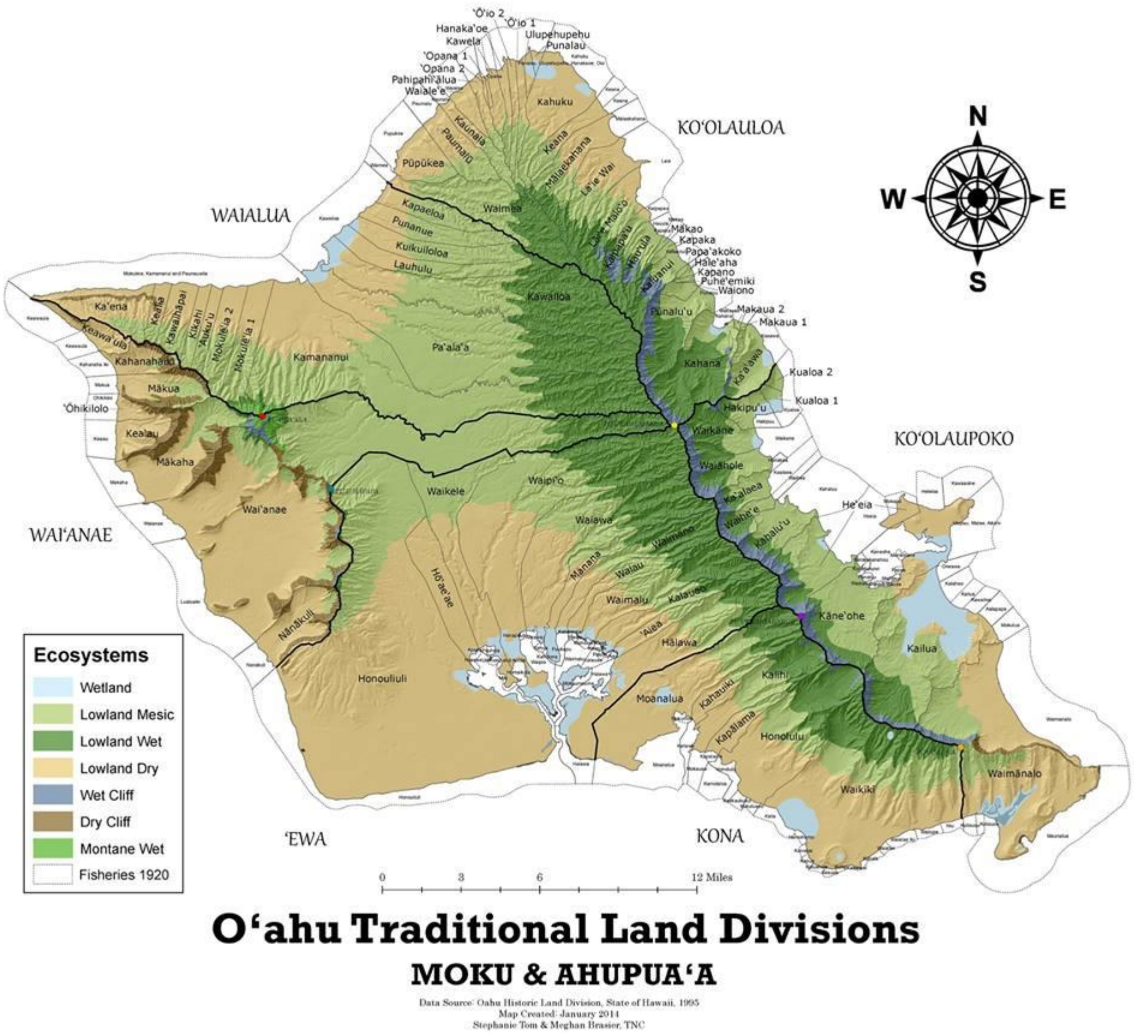

Figure 3.1. Wao Kanaka: The Hawaiian Pre-contact Ecological Footprint on O`ahu Island, and the traditional Land Divisions (moku and ahupua`a), noting that the offshore islets failed to appear on this map (Gon et al. 2014).

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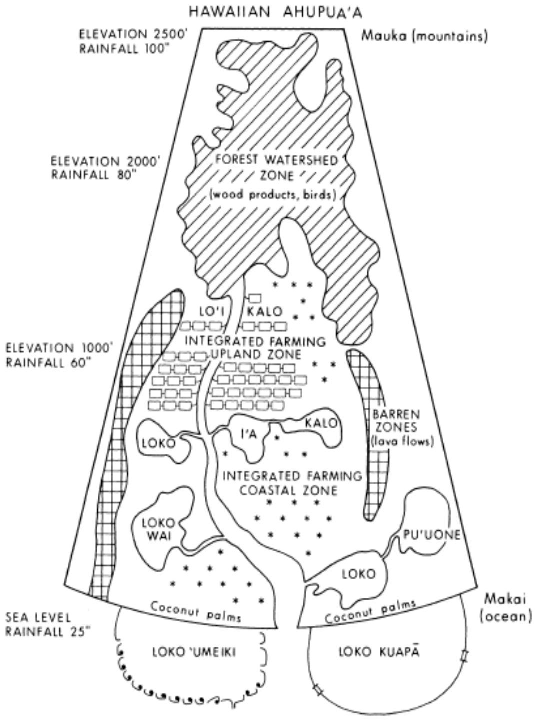


Figure 3.2. Edited image of an idealised ahupua`a showing the topographical placement of freshwater, brackish-water, and oceanic integrated farming systems (Costa-Pierce 1987). Mauka refers to the 'inland/ mountains' area, and Makai is the 'seawards/ocean' area.

Having sustained the largest population of the main Hawaiian Islands, the island of O`ahu has experienced the highest levels of fishing pressure and other human impacts (Smith 1993). The trace metal concentration in Pacific oysters, *Crassostrea gigas*, within Kāne`ohe Bay was higher than in oysters from the east and Gulf coasts of the United States mainland (Hunter et al. 1995). Additionally, this was elevated nearest urban stream mouths (Hunter et al. 1995), the same sector of the bay, which in the past, heavy freshwater flooding and increased silt were shown to result in mass mortality of benthic clams (Yap 1977). The restoration, monitoring, and improved management of integrated ecosystems along Kāne`ohe Bay have increased over the last decade. For example, He`eia ahupua`a (Figure 3.3) is a National Oceanic and Atmospheric Administration (NOAA) Sentinel Site, and a proposed National Estuarine Research Reserve (NERR).

There is a growing pluralistic approach between multiple knowledge systems within environmental management. The role of Indigenous Knowledge (IK) and Traditional Ecological Knowledge (TEK) of Kanaka Maoli in Hawai`i has increased within contemporary resource management and marine conservation research (Poepoe et al. 2003, Aswani and Hamilton 2004, Drew 2005, Jokiel et al. 2010, Hufana 2014). There is an added legislative imperative that the Hawaiian perspective and traditional methods, such as the ahupua`a management system are needed, to address the decline in environmental condition and Hawaiian cultural systems, through the `Aha Moku Act (Act 288 2012).

This present study combined scientific and socio-cultural knowledge to assess estuarine resources, landscape development, and condition, towards better management practices. This chapter focusses on the socio-cultura knowledge and landscape assessment along the north and south sectors of Kāne`ohe Bay. The following chapter focusses on the evaluation of the bivalve populations, condition, and contaminants alongside the landscape scores and socio-cultural findings from this chapter

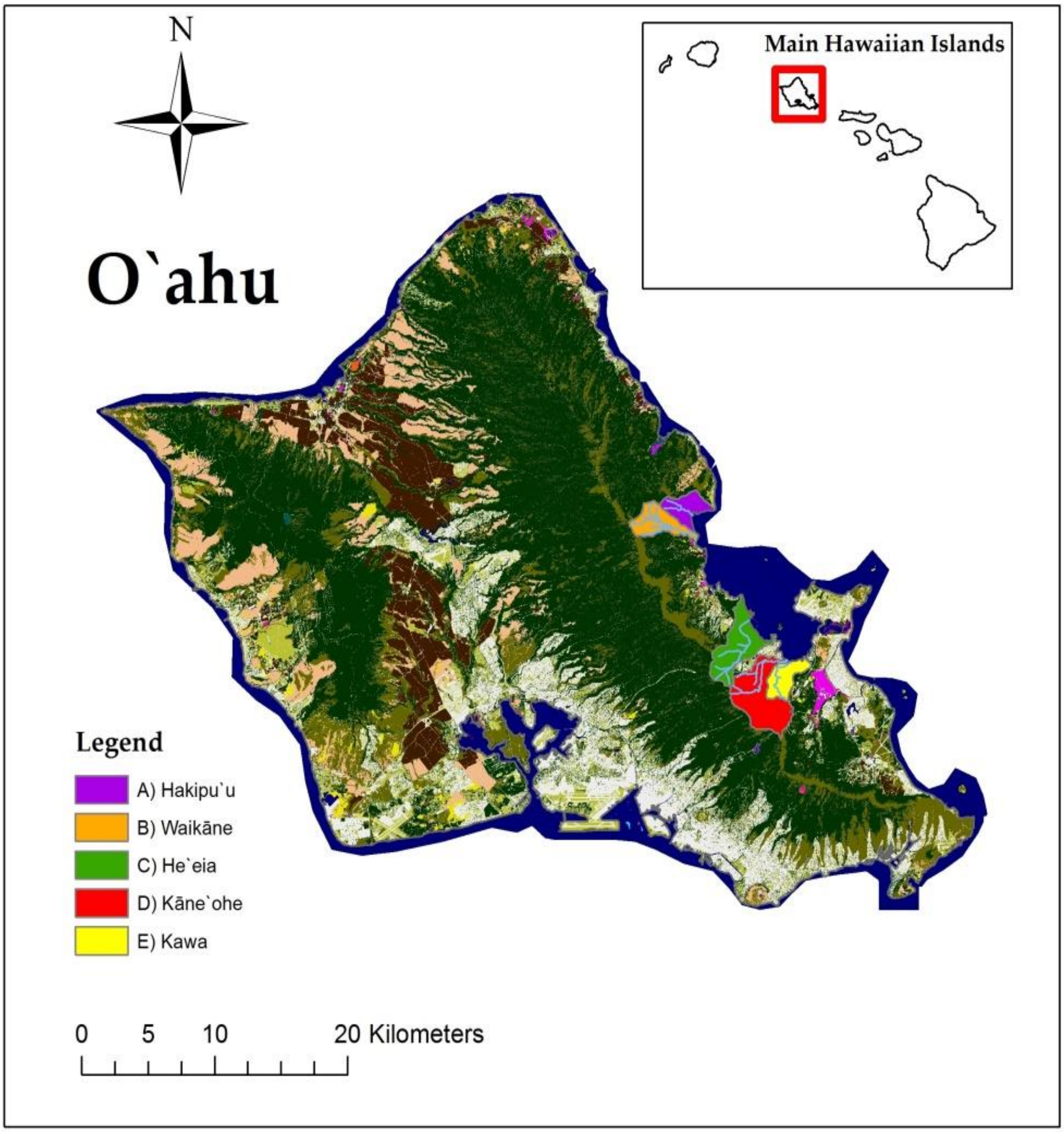


Figure 3.3. Map of O`ahu Island showing the locations of the study watersheds in this study and the main Hawaiian Islands (inset). All layers were downloaded from the State of Hawai`i website (OP 2014).

3.1.1. Social and cultural based assessments

Kanaka Maoli are reclaiming their knowledge systems towards better addressing cultural-based environmental management. Indigenous Hawaiian values in relation to conservation, ecological, historical, scientific, and educational resource protection are included within the management plan for Papahānaumokuākea Marine National Monument in the North-western Hawaiian Islands (Jokiel et al. 2010). Within Kāne`ohe Bay, a TEK project, called the Cultural Reef Assessment (CRA), was developed and used along the Kāne`ohe Bay reef systems to describe benthic structure, presence of introduced limu, native limu, and dominant reef macrofauna for traditional harvest (Kawelo 2008). Both the Cultural Health Index (CHI) and CRA have been used in study along He`eia ahupua`a in Kāne`ohe Bay (Ratana 2014). The CHI was developed for the expression of cultural based indicators by Māori in streams and waterways (Tipa and Teirney 2003) Furthermore, the cultural health index (Tipa and Teirney 2003) was found to be significantly correlated with “western” measures of stream health, as well as encapsulating the relationship between land development and stream health (Townsend et al. 2004).

Environmental management by Kānaka Maoli was respectful of the relationship between people and nature. This relationship was familial and reciprocal, and captured in the proverb:

He ali`i ka `āina, he kauwā ke kanaka

The land is a chief, man is its servant (Pukui 1983).

A marine tenure system, limited entry, minimum size restrictions, and seasonal closures are among measures recognised today as part of fisheries management in ancient Hawaii (Titcomb 1972, Johannes 1978). For example, kapu (restrictions) were placed on certain fish species including `anae/mullet (*Mugis cephalus*), he`e/squid (*Octopus* spp) , `opelu/mackerel (*Decapterus macarellus*) and other fish that bore their young in a place that was not sheltered (Titcomb 1972).

Interviewing social and recreational fishers is important to understand social and cultural based values. Marine recreational and subsistence fishing, or angling, is an important activity to many residents in Hawai`i (DAR 2015b). Fishing includes food collection and tourism activity as part of the Hawaiian economy. Hawaiian social community and recreational fishers have been included within research aimed at understanding local resource management and concerns (USAEC 1975, Smith 1993, Lowe 1995, Office of State Planning 1996, DAR 2015b). Marine Recreational Fishery Statistics Surveys (MRFSS) have been collected in the continental United States since 1979, with the those from Hawai`i begun in 2001, when they focussed on fishing trips relevant to fisheries management (DAR 2015b).

3.1.2. Study area

O`ahu Island is the third oldest of the eight main Hawaiian Islands (Figure 3.3), with 124 minor islands making up the Hawaiian Island chain. Kāne`ohe Bay is located on the windward side of O`ahu, within Ko`olaupoko Moku. This bay is unique, being the result of the coalescence of several drowned valleys and being effectively isolated from ocean waves by an extensive coral reef (Cox and Gordon Jr 1970). The Kāne`ohe Bay ecosystem consists of the watershed, the bay itself, the protecting barrier reef, and the nearshore oceanic environment. The inshore bay is generally divided into SE, central, and NW sectors (Jokiel 1991). This division was based on water circulation with the inner bay initially divided into half, with a central transition sector (Bathen 1968).

On O`ahu, the Ko`olau, or windward, climate and hydrological system is due to the position of the Ko`olaupoko Range. This range forms a sharp cliff perpendicular to the northeast trade winds, which carry moisture-laden air upward. Because it rises it suddenly contacts colder air mass, which condenses resulting in rainfall (Jokiel 1991). The O`ahu climate is subtropical (Chave 1973b) with two distinct seasons, Kau (dry season) from May-October, and Ho`oilo (wet season) from November-April (Giambelluca et al. 1986, Holthus 1986). Annual rainfall on O`ahu exceeds 250 inches a year on the Ko`olau Range while the Waianae coast receives 20 to 60 inches annually (Juvik and Juvik 1998). The annual rainfall in the Kāne`ohe region averages 140-240 cm/year (Hunter and Evans 1995). Most freshwater enters the bay from watershed runoff, with nine perennial streams (Table 3.1) that carry most of the surface freshwater discharge into the bay (Cox and Gordon Jr 1970, Jokiel 1991). The total stream discharge rate is approximately 214,000 $m^3\ d^{-1}$ (Hunter and Evans 1995), with maximum episodic storm discharges recorded of 249.2 $m^3\ s^{-1}$ in the main streams during flood events (Jokiel et al. 1993).

The islands of Hawai`i have no main river basin systems. Each of the main islands is a discrete hydrological system of streams and related drainage areas. Each hydrographic area consists of a large number of small watersheds (Office of State Planning 1996). Typically, watersheds are steep with highly permeable volcanic rocks and soils, and short, ‘flashy’ streams, vulnerable to rapid response and flooding during storm rainfall events (Office of State Planning 1996, Juvik and Juvik 1998). Many of the small watersheds are undeveloped/natural, and drain the steep pali (cliffs) on the windward sides of the islands (HCZM 1996). These have become highly eroded, deeply cut by streams and the material carried away.

Kāne`ohe Bay was essentially rural until the highways were constructed to Honolulu across the Ko`olau Range (Cox and Gordon Jr 1970). The highly integrated and diversified agriculture-aquaculture system along the bay had been subverted by many actions. This included intense resource extraction, grazing livestock, monocrop (rice, sugarcane, pineapple) plantation agriculture, stream channelisation and diversions, reef dredging, filled in loko i`a, residential homes and Kāne`ohe Town Centre (USAEC 1978, Devaney et al. 1982, Smith and Pai 1992, Laws 2000, Devick 2007). About 8.4 million cubic metres of coral were dredged between 1939-1942 to constract a seaplane landing area, and areas were filled in to contruct the Marine Core Base Hawai`i (Devaney et al. 1982, Office of State Planning 1992, Department of Health 2013a). Two major sewer outfalls were diverted from the bay in 1977 and 1978 lowering the land-derived inorganic nitrogen and phosphorus input (Smith 1981), while a smaller sewer continued discharge via a stream into northwestern sector (Smith 1981). Today, while municipal sewers serve most of the bay, the rural area sewage in the north (from Ahuimanu to Waikāne) is discharged into household sewer cesspools (Department of Health 2013a).

3.1.3. Objectives

The chapter objective was to evaluate the socio-cultural indices in Kāne'ohe Bay. The specific objectives of this chapter were to:

1. Identify who visits Kāne`ohe Bay; towards examining how their perceptions differ according to selected participant attributes: including group (Local Practitioners and Specialists and Recreational Practitioners), cultural affiliation, experience (years), and location (site/area).
2. Evaluate the traditional uses, cultural values, and the participants' main activities of the bay. To evaluate what fishery/other resource participants' favoured or targeted, and if there were any main changes to the environment or to the fishery/resource abundance(s) over time.
3. Evaluate the perceived site and catchment condition, and (if any) main changes have occurred over time.
4. Investigate if there were main environmental indicators associated with activities and values.
5. Identify management in place, and if the management was regarded as effective.
6. Calculate the catchment land condition (i.e. LDI: land development intensity index) using GIS data layers (1978 and 2005), and further changes using conventional maps (1943, 1983, and 1998) and landscape map (1973).
7. Investigate the relationships between the socio-cultural indicators and land development.

Table 3.1 The 2005 Kāne`ohe Bay ahupua`a land divisions, ahupua`a area size (OP 2005), and the associated perennial (P) and intermittent (I) streams (Cox and Gordon Jr 1970, Chave 1973b, USGS 1998), the main land use, and observed activities.

Ahupua`a	Area (m^2)	Streams	Main Land Use	Activities
Kualoa	2309690	No stream	Natural, ranch land	Camping, fishing, diving, tourism
Hakipu`u	5359662	Hakipu`u	Natural	Moli`i Pond aquaculture and eco-tourism
Waikāne	6861493	Waikāne (P) Waike`eke`e (I)	Forested, small agricultural land	Fishing
Waianu	2783766	Uwao and Waianu (I)	Residential	
Waiāhole	10223250	Waiāhole (P)	Forest reserve	Beach Park recreational activities
Ka`alaea	4558725	Ka`alaea (P)	Residential, plantation and gardens	Small boating
Haiamoa	1659027	Unnamed stream	Residential	
Waihe`e	5861749	No stream	Residential	Small boating
Kahalu`u & Ahuimanu*	11444519	Kahalu`u & Ahuimanu	Regional park, residential, urban	Tourism activities , fishing, boating, va`a/canoe
He`eia*	11506665	He`eia (P), receives ‘Ioleka`a and Ha`ikū streams	Residential, conservation, traditional lo`i kalo, gardens	State park activities for recreational and tourist, educational, fishpond restoration and education, marina fishing and larger boating, and va`a/canoe
Kea`ahala	3117172	Kea`ahala (P)	Residential, Hawaii Institute of Marine Biology facilities on Moku o Lo`e.	Boating and yachting.
Kāne`ohe*	14732948	Kāne`ohe (P), receives Kapunahala, Kamo`oali`i, and Luluku.	Urban park land, botanical garden, forest reserve, and reservoir	Beach Park fishing, activities on the private pier, boat launch
Kāwā*	5408480	Kāwā (P)	Urban, urban grassland, and quarry	Waikalua loko i`a maintenance and science, technology, engineering and mathematics (STEM) programme.
Pu`u Hawaiiloa*	9437347	No stream	Urban, residential, conservation, military land use	Nu`upia Pond, yachts, sailing, kayaking, boat launching.

*Traditionally He`eia and Kāne`ohe ahupua`a extended across the Bay to what is now called the MCBH base on Mokapu Peninsula. Today Mokapu Peninsula is mapped within the Pu`u Hawaiiloa watershed. Kāwā was not in the traditional map (Figure 3.1) however, it was a separate watershed basin within the GIS map layers.

3.2. Methods

This section provides the research methodology for evaluating the socio-cultural values in Kāne`ohe Bay. Chapter 2 provides the overall interview methodology and analysis, the Landscape Development Intensity (LDI) index, and statistical analyses.

3.2.1. Site selection

There are fourteen ahupua`a with nine perennial streams within the Ko`olaupoko Moku with nine of these in the Kāne`ohe Bay area (Figure 3.3, Table 3.1). Sites were selected based on access and areas where there were people to interview. The State Parks and Beach Parks were open to public use and State permission was granted to carry out the environmental component of this research. To provide anonymity to the participants, the survey information from participants was grouped into the north (n=9) and south sectors (n=12), and one participant fished offshore.

3.2.2. Landscape development assessment

The seven shellfish watersheds, streams, and land use land cover (LU/LC) along Kāne`ohe Bay were mapped from the 1978 and 2005 GIS data layers provided by State of Hawai`i Office of Planning (OP 2014). The land development scores and interview indices was correlated. Visual analyses were made using the 1978, 1983, and 1998 conventional maps of Kāne`ohe Bay (USGS 1943, 1983, 1998).

3.2.3. Interviews, narratives, literature analysis

A questionnaire was used to survey Recreational Participants (RP) across the bay, while an interview approach with space for dialogue was undertaken with Local Practitioners and Specialists (LPS). The interviews were all conducted in English, but many participants referred to local Hawaiian and Indigenous Hawaiian terms and concepts. Following the interview, transcribing, and review process, mixed methodology analysis was undertaken, as described in Chapter 2 (Section 2.3). Narratives and literature were sourced to provide context to given quotes, themes, and discussion from interviews, for instance other Hawaii fishery interviews (Maly and Maly 2012) and traditional Hawaiian proverbs and sayings (Pukui 1983). Recreational Participants (RP) consisted of 'beach-goers', fishermen, divers, of whom were intercepted and met at a range of locations around each of the sites. Local people recommended other recreational persons, eco-educational or tourism operators in the bay, who were contacted, and three RP were interviewed. Two local fishers were associated to the community of cultural-based ecosystem programmes, and later interviewed. Local Practitioners and Specialists (LPS) consisted of local authority members, environmental practitioners, managers, lawai`a (fisherman/fisherwoman), and residents who had long-term experience within the area. Engagement, discussions, and interviews were done face to face using a voice recorder. The duration of each LPS interview ranged from 22 to 120 minutes. Recreational fishers were difficult to interview as they were preparing to leave the shore, cleaning up, or returning home. Tourist and local beach goers located in the northern sites declined to participate. My status as an outsider limited the number of LPS interviews, which was understandable.

Natural resource categories

The frequency of target and favoured fishery resources had a low sample number due to the diversity of fishery species given and the low number of interviewed participants. To compare fish species abundances, they were further categorised by the fish classification by scientific family and within additional groups (i.e. introduced plants, fish, and shellfish). The common name, Hawaiian name, or scientific names were given for the following organisms: lobster, crab, and limu/algae. These three species were combined for the analysis. The native pickleweed was removed from the analysis because no taxonomic information or literature in Hawai`i could be found for native species, but the introduced species was kept.

3.2.4. Statistical Analysis

The sample data were entered into Excel™, grouped by location, the north (n=9) and south (n=12) sectors, and by participant groups, RP (n=13) and LPS (n=8). These groups were not analysed by intra-group classifications (i.e. age and cultural affiliations) due to low numbers. Participant experience was also grouped into either less experienced (<10 to <20; n=13) or more experienced (20 to 30 years; n=8), except when running correlation analyses, which four period groups were used (<10/10/20/30 years). The offshore participant was excluded from the analysis. It is further noted here that some participants had a longer experience period in the bay, however reference points were made to provide comparative time periods between participants. All statistical analyses were done using Statistica Software Version 13, and statistical significance was set at α=0.05.

The Fisher's exact test was used to analyse the nominal answers relating to main activities, environmental condition, and management. These were compared across participant group, location, or experience. The assumption of sample size (cell count) was not met, and the independence assumption was met, supporting the use of Fisher's exact test rather than the chi-square test.

To investigate the relationships between variables, a correlation analysis was used to analyse the relationship between perceived fishery resources and participant experiences (tests=81). Correlation analysis was used to test the relationships between perceived fish species informationwith participant experience (tests=100). A correlation analysis was also used between socio-cultural indicators, participant experience, and landscape indices (the LDI index and impervious surface area; tests=225).

Since the perceived fishery variables and the landscape indices did not meet the normality assumptions, and various transformations did not improve normality, the Spearman rank analysis was used to examine the two correlation groups.

Within the grouped fishery types, an additional group was calculated to exclude P`apio (young barred jack, *Caranx ignobilis*) from the associated group because it had likely over-represented the family because it was the most highly mentioned fish. A problem with multiple variable correlations is that there could be a high number of false discovery rates (FDR) (McDonald 2009). The Benjamini-Hochberg procedure controlled for this, with a FDR of 5%, specific methods given in Chapter 2.

3.3. Results

3.3.1. Participant descriptions

Fourteen Recreational Participants (RP) and eight Local Practitioners and Specialists (LPS) were interviewed during this study in nine ahupua`a across Kāne`ohe Bay (Table 3.2). The participants' age group ranged between 21 to 80 years old. There were more male (59%) than female participants (41%), a higher proportion of participants located in the South section (55%) than the North (41%) and an offshore fisherman. Many participants identified as Kānaka Maoli/Native Hawaiian, and were also culturally affiliated as Caucasian, African, and Asian. Other participants identified as Asian, Caucasian and Arabian. All but one LPS resided in their familial ahupua`a within the bay, with one person now living in the next town over. The next town over resides within the same regional boundary of Ko`olaupoko Moku. Half of the RP resided within the Kāne`ohe Bay area, while two travelled from the windward side outside the Ko`olaupoko moku, and five travelled from across the island. Some of the ahupua`a (Hakipu`u, He`eia, Kāne`ohe, and Kāwā) where participants were interviewed aligned with the shellfish sites of this study. The type of access and activities varied at these locations, for instance, all loko i`a and piers were privately owned and managed, and would include educational, restoration, or ecotourism programs, while beach parks, state parks, and public marinas were open to public. There was no public access to certain boat marinas and all military areas.

3.3.2. Site information and activities

The historical and current value of Kāne`ohe Bay was discussed with LPS. Each site, was referenced to an ahupua`a, that held cultural, recreational, and traditional values. According to one participant, people identified with their local ahupua'a; the ahupua`a was more than a land division, it was the social-political-economic unit of life. Cultural importance was captured within "*He `ōlelo no`eau*" (LPS), the traditional stories and names given across the bay. For instance, Waikāne, the name of a northern ahupua`a, was explained by a participant to be water (derived from wai) and man or an environmental god/deity (after Kāne). This highlighted Waikāne as a historically important source of freshwater to the bay as it was captured in traditional story. The bay was a meeting place of King Kāmehameha and chiefs from the Hawaiian Islands (LPS). Previous activities included commercial, recreational, and loko i`a fishery. Current uses of the bay included educational programs, eco-tourism, commercial, and recreation. Many of the uses were around family interacting in the bay, including fishing and recreation as a family, paddling va`a/outrigger canoe, diving. Instead of 'going fishing', "*We say we go holoholo, this is to cruise, because the fish have ears*" (LPS). Loko i`a were traditional and culturally important sites aged at 400-800 years old.

All LPS primarily fished, gathered, and dived for resources, a few collected pōhaku/stones, shells, and wood (63%). Pōhaku were used for building and restoring loko i`a walls, whereas shells were collected for sentimental reasons. Few LPS undertook leisure activities (63%) such as surfing, stand up paddle boarding, walking, camping, and boating (Table 3.2). Knowledge of habitat type and fishery species were long term and extensive. Most RP who participated fished (71%) and did leisure (57%) within the bay. Few RP collected shells and stones (21%) for ornamental and sentimental reason. Leisure activities included kayaking, camping, sailing, and boating. Fishing regulations and protocol results are provided in the 'Management and Practices' section.

The traditional function of loko i`a was to enhance brackish environments for raising/culturing herbivorous shellfish/fisheries – including oysters and native clams for commercial or research purposes. As part of raising herbivorous shellfish/fisheries, it was important to remove of predatory and invasive species from the loko i'a. The loko i`a were also utilised for ecotourism, or to deliver Hawaiian cultural-based `āina education, or STEM (science, technology, engineering, mathematics) programmes. Loko i`a organisations hosted the public and schools who assistant to maintain and restore the loko i`a, as well as learn about these traditional systems.

Table 3.2. The number of Local Practitioners and Specialists (LPS), and Recreational Participants (RP), who participated in the following activities in Kāne`ohe Bay.

Area	Group (n)	Site visits per month	**Activity of interest (number participants)**			
			Fishing/Gathering/ Diving	Collecting stones/shells/wood	Leisure	Other activity
North	LPS (n=5)	20 (4-30)	100%	60%	60%	20%
	RP (n=4)	11 (2-30)	75%	25%	100%	No value
South	LPS (n=3)	19 (9-30)	100%	67%	67%	No value
	RP (n=9)	13 (9-17)	89%	22%	56%	11%
Offshore	RP (n=1)	30	100%	No value	100%	No value

3.3.3. Socio-cultural indicators

Natural resources favoured/targeted

The fishery resources presented here are those mentioned by many of the participants (95%) who fished, harvested, crabbed, and dived (Table 3.2). Participants named forty-nine native fish, five native plants, three introduced fish, two introduced shellfish, and three introduced plants (Table 3.3). The perceived abundances of the following resource: i`a/fish, ula/ 'lobster', and pāpa`i/crab, were combined due to general names given (Figure 3.4). Interviewees called crayfish - ula or lobster, and octopus - he`e or squid. Three lobster names included 'lobster', spiny lobster, and slipper lobster. The banded spiny lobster, *Panulirus marginatus*, belongs to the Palinuridae family, the sculptured slipper lobster, *Parribacus antarcticus*, and blunt slipper lobster, *Syllarides squammosus*, both belong to the Scyllaridae family.

The LPS in the north listed a higher diversity of fishery resources than all other groups (Figure 3.4). They were the only interviewees to mention sea chubs (Nenue), mackerels (Ono), filefish (`Ō`ili), silvery toothless (Awa), and wrasses (Wrasse in general and Hīnālea). The i`a/fish (5.2-23.5%), introduced plants (1.7-28.6%), jacks and pompanos (10.3-23.6%) were the most frequently mentioned groups. Jacks and pompanos included five species - ōmilu, omaka, ulua and pāpio (both same species), akule, and `opelu (See Table 3.3). Only the LPS individuals mentioned introduced plants, `anae (mullets; 4.8-5.2%), and awa`aua (tenpounders; 3.4-4.8%). Furthermore, introduced plants were mentioned more frequently that native plants, which included the Japanese Gorilla Ogo, *Gracilaria versa,* introduced pickleweed, *Batis martima*, and mangrove, *Rhizophora mangle*. These plants were harvested for consumption, as well as targeted removal as permitted in loko i`a, as well as research projects in the bay. Other targeted removals, included predator fish (e.g. tō`au, barracuda) and invasive algae from loko i`a. Both more experienced RP and LPS, targeted introduced fish and less favoured species, to minimise their pressure on native populations.

Native crabs were also most commonly mentioned (5.2-17.1%) by fishers, excluding the RP in the southern section (Figure 3.4, Table 3.3). Similarly, all interviewees, except the RP of the south, mentioned lobster, introduced fish, and native plants. Squid/he`e (*Octopus* spp.) and barracuda/kākū (*Sphyraena barracuda*) were mentioned by LPS in both sectors and only northern RP. Shellfish (1.7-5.2%), sea urchin/wana (*Echinothrix calamaris*; 1.7-5.9%), and threadfins/moi (*Polydactylis sexfilis*, 1.7-2.9%), were the least mentioned. Shellfish were additionally cultured within loko i`a for commercial or aquaculture research trials. Natural/wild stocks elsewhere in the bay were restricted from harvest. Those who spoke of shellfish in the bay were from personal experiences or from those of the older generation. Furthermore, shellfish, moi, along with adult barred jack/ulua (*Caranx ignobilis*), parrotfish/uhu (spp.), native crabs (spp.), and lobsters (spp.), were reported to have declined or were no longer available (Table 3.4).

The oyster and clam fishery have remained closed for at least a generation (>30 years), and according to a LPS, shellfish in Hawai`i were traditionally sparse items to supplement a meal. Clam harvesting was experienced by older participants and knowledge passed only by story to younger participants (~30-year-old). Two LPS remembered gathering oysters in the north for recreation and consumption. The back of the shells would remain on the attached rock, and repopulation would occur over time. According to a northern LPS, the population of the commercially cultured *C. gigas* has successfully increased in the northern loko i`a. An LPS mentioned that the oyster fishery closed due to shellfish decline, and two participants mentioned oysters had declined (Table 3.4).

According to participants, clams were harvested on the mudflat in the 1960s up to 1969, includingKāne`ohe Beach Park and further around the southern-most site. Harvest allowed 1 gallon per person, and due to the abundance, no shovel was required. At one point, several hundreds of people had gathered there with wire cages to sieve the clams. Larger sizes were selected with good growth rate due to the sewer outfall and fertiliser at the time. The reasons given for the fishery closing included the decline in water quality and run-off, with town housing development; the harvesting pressure from increasing population; and food safety risks from sewer pollution. The sewer stopped discharging into the bay in the 1970s, coinciding with declined clam beds, which was perceived to bedue to both less sewer nutrients and over harvesting. Five people spoke of clams declining or no longer remaining (Table 3.4).

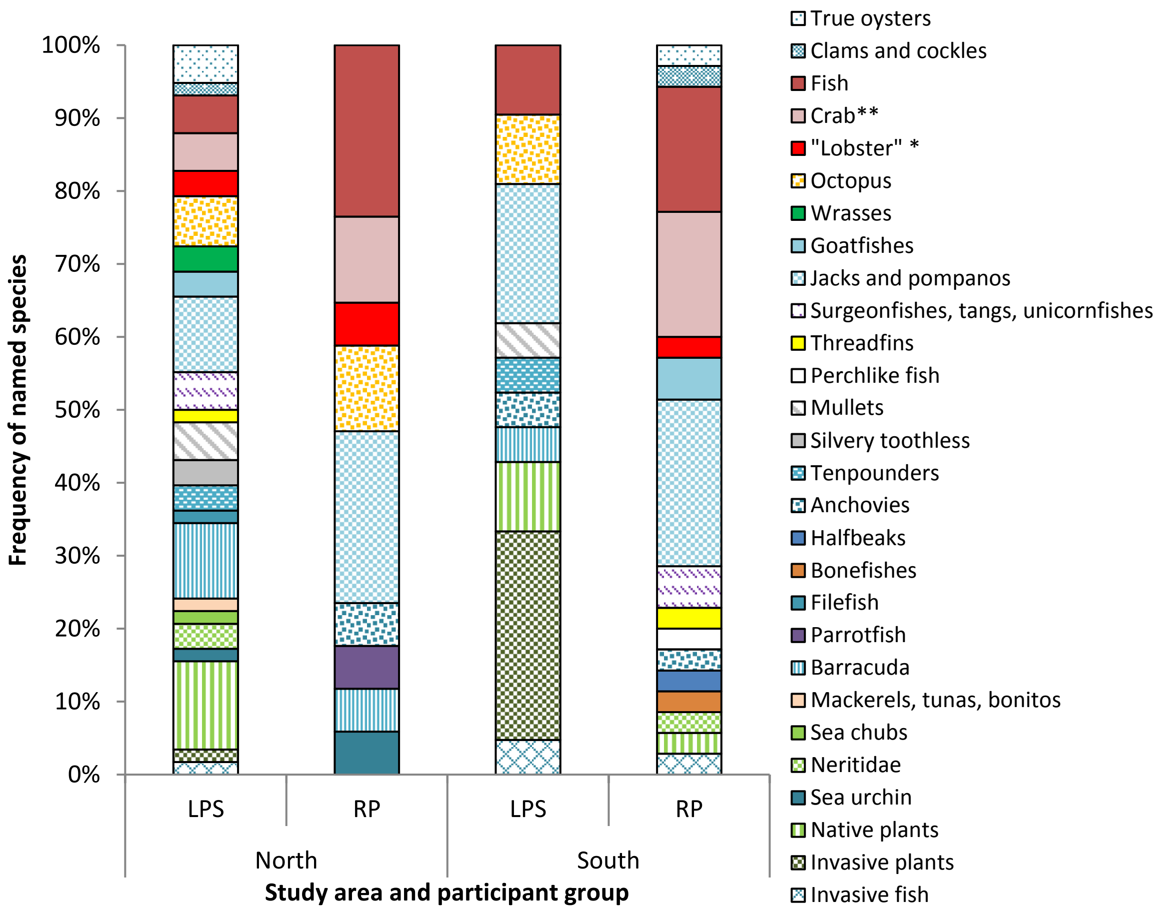


Figure 3.4. The percent frequency of named fishery organisms favoured by Local Practitioners and Specialists (LPS) and Recreational Participants (RP). The organisms were grouped by scientific family where possible and the classification is provided in Table 3.3.

Table 3.3. List of named fishery species, with Hawaiian name, general name, and scientific classification.

Family	Common family	Hawaiian name	General name	Genus	Species
Albulidae	Bonefishes	\`Oio	Bonefish	*Abula*	*vulpes*
Hemiramphidae	Halfbeaks	Ballyhoo	Marine halfbeak	*Hemiramphus*	*brasiliensis*
Engraulidae	Anchovies	Nehu	Sardine, Hawaiian anchovy	*Encrasicholina*	*purpurea*
Elopidae	Tenpounders	Awa\`aua	Hawaiian ladyfish, Hawaiian tarpon	*Elops*	*hawaiensis*
Chanidae	Silvery toothless	Awa	Milkfish	*Chanos*	*chanos*
Mugilidae	Mullets	\`Anae	Striped mullet (adult)	*Mugil*	*cephalus*
Kuhliidae	Perchlike fish	Aholehole	Perchlike fish (adult stage)	*Kuhlia*	*sandvicensis*
Polynemidae	Threadfins	Moi	Pacific/six-feeler threadfin	*Polydactylis*	*sexfilis*
Acanthuridae	Surgeonfishes, tangs, unicornfishes	Kala	Unicorn fish	*Naso*	*hexacanthus*
		Manini	Convict tang surgeonfish	*Acanthurus*	*triostegus*
		Kole	Goldenring (surgeonfish)	*Ctenochaetus*	*strigosus*
		Palani	Eyestripe surgeonfish	*Acanthurus*	*dussumieri*
Carangidae	Jacks and pompanos	Ōmilu	Bluefin trevally	*Caranx*	*melampygus*
		Omaka	Yellowtail scad/Jack	*Atule*	*mate*
		Ulua	Barred jack (adult)	*Caranx*	*ignobilis*
		Pāpio	Barred jack (young)	*Caranx*	*ignobilis*
		Akule	Big eyed scad	*Selar*	*crumenophthalmus*
		\`Opelu	Mackerel scad, cigarfish	*Decapterus*	*macarellus*
Mullidae	Goatfishes	Kūmū	White saddle goatfish	*Parupeneus*	*porphyreus*
		Weke	Goatfish	*Mulloidichthys*	spp.
		O\`ama	Goatfish (young Weke)	*Mulloidichthys*	spp.
Labridae	Wrasses	Hīnālea	Bird wrasse	*Gomphosus*	*varius*
		Wrasse	Wrasses		
Kyphosidae	Sea chubs	Nenue	Hawaiian Chub	*Kyphosus*	*hawaiensis*
Scombridae	Mackerels, tunas, bonitos	Ono	Wahoo	*Acanthocybium*	*solandri*
Sphyraenidae	Barracuda	Kākū	Barracuda	*Sphyraena*	*barracuda*
Scaridae	Parrotfish	Uhu	Parrotfish		spp.
Monacanthidae	Filefish	\`Ō\`ili	Filefish/broomfish/broom leatherjacket	*Amanses*	*scopas*
Diadematidae	Sea urchin family	Wana	Banded sea urchin	*Echinothrix*	*calamaris*
Octopodidae	Octopus	He\`e	Octopus, tako, "squid"	*Octopus*	spp.
Neritidae	Marine snails	Pūpū	Snail		spp.
		Kūpe\`e	Polished nerite (snail)	*Nerita*	*polita*
Lycopodiaceae	Native plants	Limu wawae\`iole	Mann's clubmoss	*Hyperzia*	*mannii*
Bonnemaisoniaceae		Limu kohu	Pleasing seaweed', red algae species	*Asparagopsis*	*taxiformis*
Gracilariaceae		Native (with Japanese-derived name) Ogo	Native *Ogo*	*Gracilaria*	*parvispora*
Gracilariaceae		Limu manauea	Endemic edible seaweed	*Gracilaria*	*coronopifolia*
Portunidae	Introduced fish	Samoan crab	Mangrove carb, mud crab	*Scylla*	*serrata*
Lutjanidae		To\`au	Blacktail snapper	*Lutjanus*	*fulvus*
Belondinae		Stickfish	Needlefish	*Strongylura*	spp.
Veneridae	Introduced shellfish	Clam	Butterclam, Japanese clam	*Tapes/Ruditapes*	*philippinarum*
Ostreidae		Oyster	Pacific oyster	*Crassostrea*	*gigas*
Bataceae	Introduced plants	Pickleweed	Saltwort/beachwort	*Batis*	*maritima*
Rhizophoraceae		Mangrove	Red mangrove	*Rhizophora*	*mangle*
Gracilariaceae		Japanese ogo	Ogonori	*Gracilaria*	spp.

Table 3.4. The percent frequency of Local Practitioners and Specialists (LPS) and Recreational Participants (RP) who perceived declines in natural resources at Kāne`ohe Bay. The general, Hawaiian and scientific names are provided (Table 3.3).

Species	North		South		The bay
	LPS	RP	LPS	RP	Total
Clams	20%	25%	67%	11%	24%
Pacific oyster	40%				10%
Mullet	20%				5%
Moi				11%	5%
Ulua		25%			5%
Crab	20%			11%	10%
Lobster	20%	25%			10%
Kūmū	40%				10%
Uhu	20%	25%			10%
Wawae'iole	40%				10%
Manueaua	40%				10%
Limu kohu	20%				5%
Limu lipeepee	20%				5%
Limu (general)				11%	5%

Resource abundance

The evaluation of natural resources includes both quantitative (Figure 3.5, Table 3.4) and qualitative (Table 3.4) knowledge from interview participants. Only long-term fishers reported natural resource decline (Table 3.5). The perceived abundances of ten fishery species (reported by ≥3 participants) differed between fisher experience (years). Those with less experience in the bay (<20 years) generally reported higher abundances than those who had longer periods and lifetime experience in the bay (Figure 3.5). For example, higher abundances were reported for the following species by less experienced fishers: pāpio, introduced limu, introduced crab, omaka, and oysters. Additionally, fishers with less experience did not mention the abundance of lobsters and clams, compared to more experienced (20-30 year) fishers, while little experience (≤ 10 years') did not mention He`e. Additionally, the relative abundances for pāpio according to more experienced fishers contrasted to each other, at 10% and 100% (mean= 90%). However, pāpio and mullet were restocked by the State, as highlighted by qualitative responses, likely supported variability in perceived abundance. Although the perceived relative abundance varied according to fisher experience, only the the introduced crab was significantly negatively correlated with participant experience ($r= -0.89$, $p<0.05$, Table 3.6).

During the interview on perceived abundance of these aquatic species, interviewees provided additional indicators of fishery and ecological changes (Table 3.5). For example, catch per unit effort has increased for the native crabs and lobster species. The plant-and-habitat association, has shifted from native limu on certain reefs to invasive limu along these reefs. An increase in the invasive Japanese ogo has occurred, while the limu manueaua and other limu decreased. The decline in fishery practice (such as using nets) and the decline in fishermen presence, are indicative of decreased abundances. This decline was associated with lobsters and native fish.

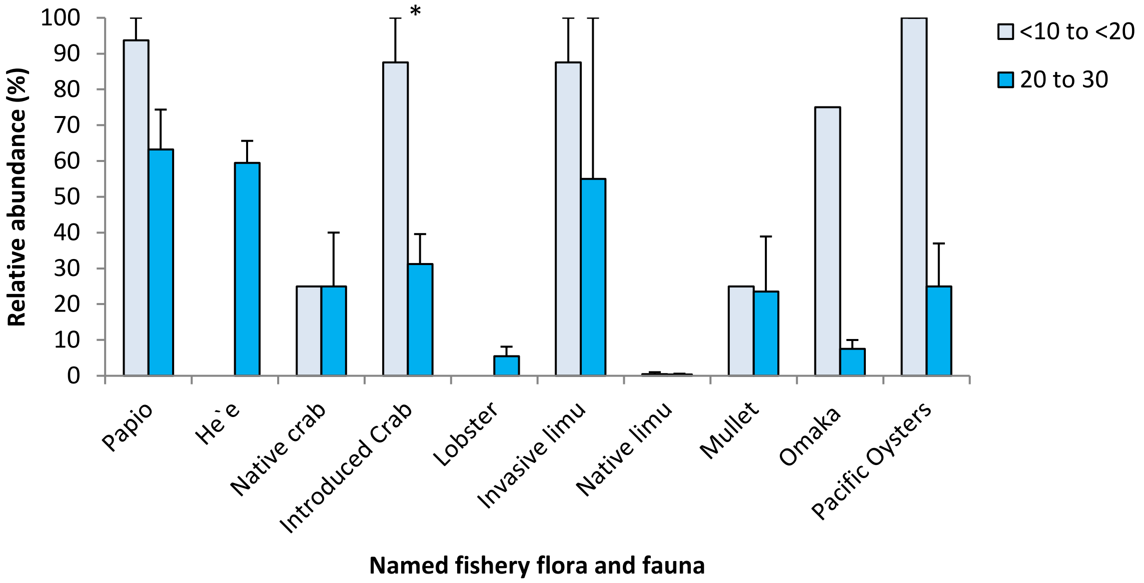


Figure 3.5. The mean (±S.E.) perceived relative abundance (%) of flora and fauna species grouped by participant experience (<10 to <20 and 20-30 years). There is no S.E. where n=1. Significance (*) between perceived abundance with fisher experience.

Table 3.5. Examples of key phrases and themes relating to the participants' perception of the state of the local fishery.

Theme	Examples of key phrases
Decreased catch per unit effort	*Within the fishpond, the native crab catch has reduced. In 2000-2005, they would drop 20 nets and catch 52-100 crabs, now catching only five crabs. The Samoan crab fluctuates due to harvest pressure. 'Went down to the point last week to go crabbing, two months ago, caught one large five pound and two pound. Eight traps were set, the rest were empty. Before, every trap would catch one'*
Declined native resources and increased introduced/invasive species	*'All of the fringing reefs, following the entire bay is where we use to get all the [limu] manueaua and now there is nothing'* *'Native limu is no longer because of the invasive plants, aquatic and terrestrial'.* *'The spiny Ogo has invaded the site where limu manueaua was harvested in the past (<30 years).'* *'Lobsters is terrible, don't even go for lobsters anymore' 'Spiny lobster is no longer available in the bay' 'The lobster was abundant, is now 0-2%, crabbing is now dismal, at about 10%. Used to always go crabbing, but do not go anymore. The participant no longer fishes for mullet anymore either, it has declined to about 10%.'* *'The introduced species, the ta`ape (bluestripe snapper (Lutjanus kasmira), to`au (blacktail snapper: Lutjanus kuvrus), roi (peacock grouper: Cephalopholis argus), crabs effect the ecosystem of the lobster. They eat them, they eat the [juveniles]'* *'He`e compared to when a kid is different, because all the reefs here, we got 150 reefs, we call them poepoe, papa, used to have choke squid on them'* Note: 'Choke squid' means a very high abundance of octopus.
Fishing and gathering practices have changed over time	*'The proper practice for harvesting limu manueaua, were to pick them from their base, and not to pick those with bumps/reindeer antlers. Some people did not do this, and some had even taken the limu attached to rocks.'* *'We used to catch mullet with the net…if your practices have changed that you discontinue going out with a net, then that automatically tells you that the resource has changed, either that or you too old to go'* *'Well a lot of commercial [fishers] they were catching…40000 pounds of lobster tails, and now they made the law. Now I don't see [any] body catching lobsters'*

Table 3.6. Correlation between participants experience (years) and the perceived abundance of fish, corrected using the Benjamini-Hochberg critical value (i/m*Q) (Q=0.05) Significant values are in bold, potential significance italicised, and the spearman coefficient (R) and p-value are given.

	Participant experience		
Fish	R	p-value	(i/m*Q)
Introduced crab	**-0.892**	**<0.05**	0.02
Pacific oyster	-0.667	0.15	0.04
Papio	-0.384	0.20	0.07
Omaka	-0.866	0.33	0.11
Invasive limu	-0.389	0.61	0.13
Native crabs	-0.500	0.67	0.16
Mullet	0.177	0.78	0.18

3.3.4. Landscape evaluation

Landscape evaluation by participants

Historical landscape uses and changes mentioned by participants in Kāne`ohe Bay included agricultural uses and landscape development in the south, with waterway alteration in both sectors of the bay (Table 3.7). Loko i`a were replaced by landscape development, and streams diverted away from loko i`a, and channelised. These changes were evident in conventional and the GIS-created LU/LC (see the following section). Moli`i loko i`a was divided into two sectors was not shown on 1978 LU/LC map (Figure 3.6), however, it was shown in the 1943-1978 conventional maps and 2005 LU/LC map (Figure 3.7-3.9). Historically, Kahalu`u was known for its extensive lo`i kalo (according to a Local Practitioner Specialist/LPS), and so was He`eia (Personal Communications 2014). In 1943, the maps depicted clear landscapes at these ahupua`a, while in 1978, the multiple agricultural lands in Kahalu`u and a large agricultural section in He`eia was evident (Figure 3.9). The later 2005 LU/LC map classified marsh/swamp land and mangrove symbols, near the streams in both ahupua`a indicating wetlands (Figure 3.7). The current restoration of lo`i kalo, in the marsh/swamp land of He`eia, indicates these landscapes were associated with lo`i kalo systems (Personal observation 2014).

All the LPS and half of the Recreational Participants (RP) group agreed that main landscape or inner bay changes have occurred over their time. Both groups perceived negative impacts on the bay's ecosystem that were associated with the main changes in the environment (Figure 3.10), and these are further discussed in the next section. The most frequent main changes were catchment land use, water flow and diversion, water quality, and sediment condition. Mud and debris entered the bay via streams in Kualoa, Kahalu`u, Kāne`ohe, and He`eia (RP and LPS). An example given of stream alterations was that two streams that traditionally flowed into Waikalua loko i`a, hence its name of ‘the two waters’. Further analysis of stream alterations follows below within the GIS landscape section. Frequently mentioned by northern participants, was the decrease in water input at Waikāne and Waiāhole ahupua`a due to water diversions from the windward side to other side (`Ewa Moku – one of the main O`ahu districts, which is located on the leeward side).

This perceived observation of main changes was significantly higher for LPS compared to RP (v^2=5.43, DF=1.0, $p<0.05$), rather than participant location or experience. The individual changes (catchment land use, water flow and diversion, and sediment) could be analysed statistically, while the others did not have enough samples across the sites. Changes to water flow/diversion was perceived higher by LPS than RP (v^2=5.42, DF=1.0, $p<0.05$) with no difference across experience or location. The perceived change in catchment land-use was perceived higher by more experienced than less experienced persons (v^2=5.47, DF=1.0, $p<0.05$), with no difference across location or group. Sediment was not significantly different across either variable.

Table 3.7. Historical land and bay uses in the north and south sectors according to all participants.

North sector	South sector
• Loko i`a historically split into two sections • Stream diverted away from loko i`a • Traditional lo`i kalo lost • A loko i`a is no longer active, filled in with concrete • Stream channelised • Water diversion	• Agriculture and plantation (i.e. rice, pineapple, and cattle) • Residential and urbanisation development • Building of the Marine Core Base Hawai`i (MCBH) in 1937 • Other military occupation and activities – including the dredging of reefs to land military sea-planes • A dumping site near a southern loko i`a • Sewer treatment discharge • Stream input altered: Kāwā stream diverted for dairy in the 1960s • Stream altered and channelised: Kāne`ohe stream • Loko i`a replaced by residential development

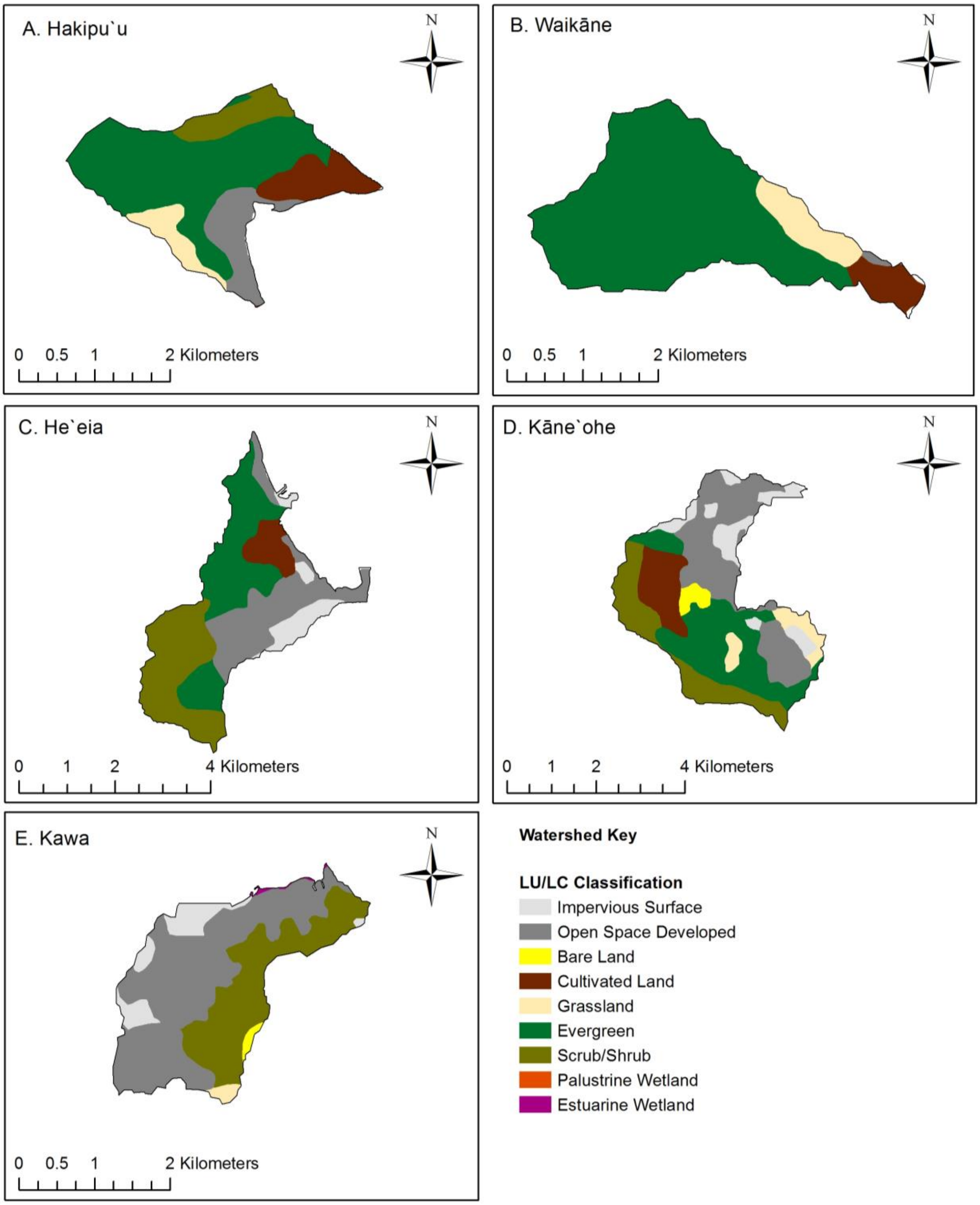


Figure 3.6. The 1978 land use land cover (LU/LC) classification of the study ahupua`a listed from north to south in Kāne`ohe Bay (OP 1978).

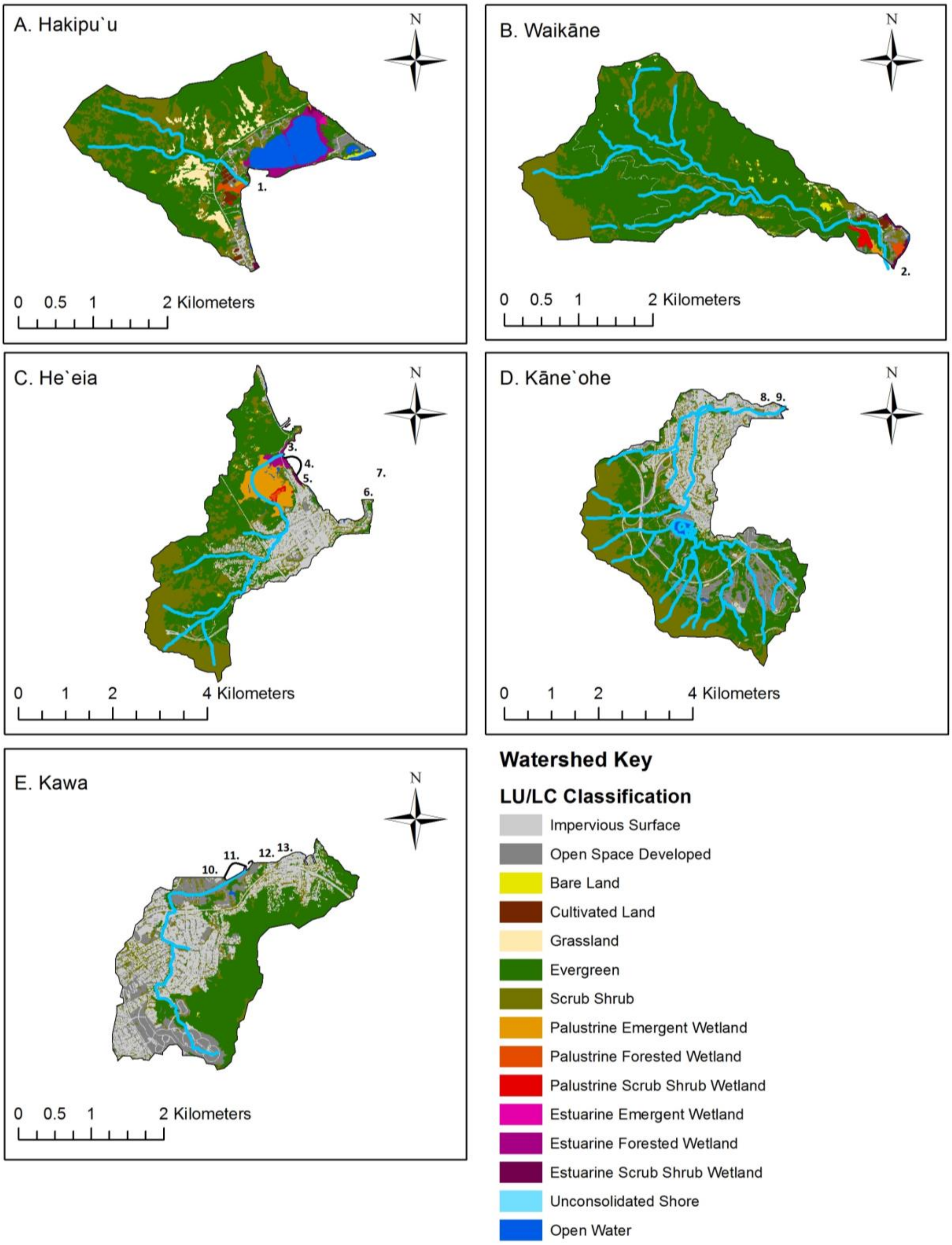


Figure 3.7. The 2005 land use land cover (LU/LC) classification of the study watersheds listed from north to south in Kāne`ohe Bay (OP 2005), as well as the shellfish study sites (numbered 1-13). The watersheds (A-E) in reference are provided within the O`ahu Island map (Figure 3.3). Note: Site 7 (Moku o Lo`e) is the inner island that sites adjacent to Site 6 (Lilipuna Pier).

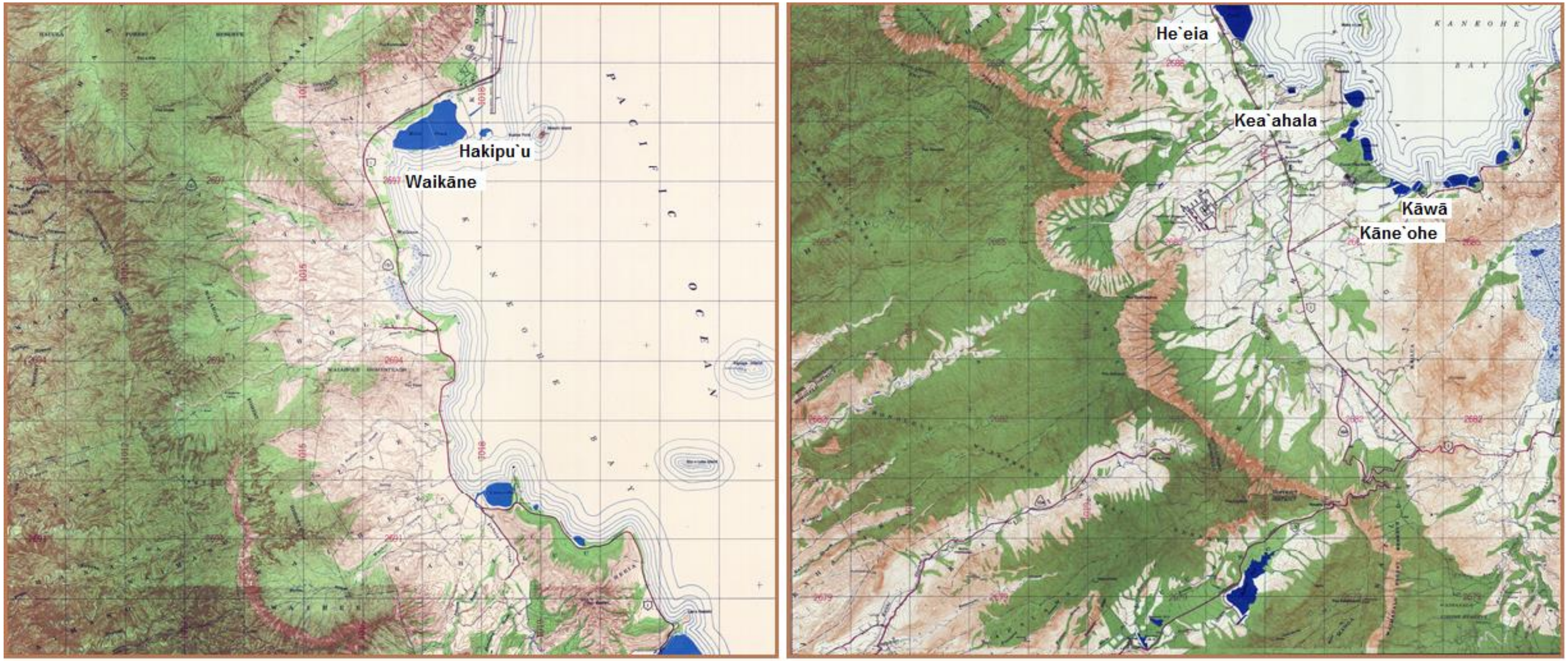


Figure 3.8. The 1943 conventional maps of Kāne`ohe Bay with fishponds in blue, and inclusive of the study ahupua`a areas (Hakipu`u, Waikāne, He`eia, Kea`ahala, Kāne`ohe, and Kāwā)) (Left), (USGS 1943).

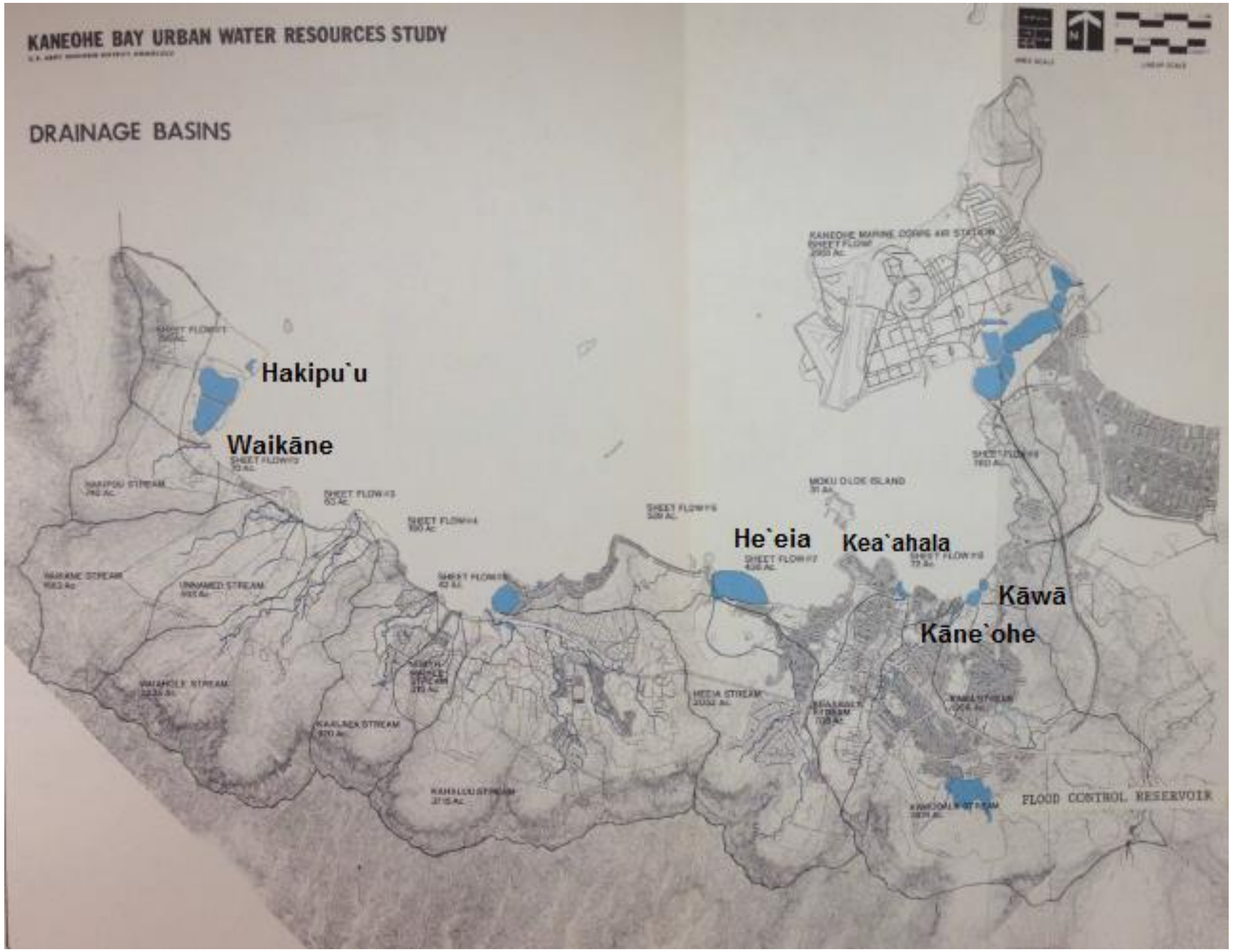


Figure 3.9. The 1978 drainage basins (similar to many of the ahupua`a divisions) of Kāne`ohe Bay with loko i`a and flood control reservoirs highlighted (blue) (USAEC 1978) , and the study ahupua`a (Hakipu`u, Waikāne, He`eia, Kea`ahala, Kāne`ohe, and Kāwā).

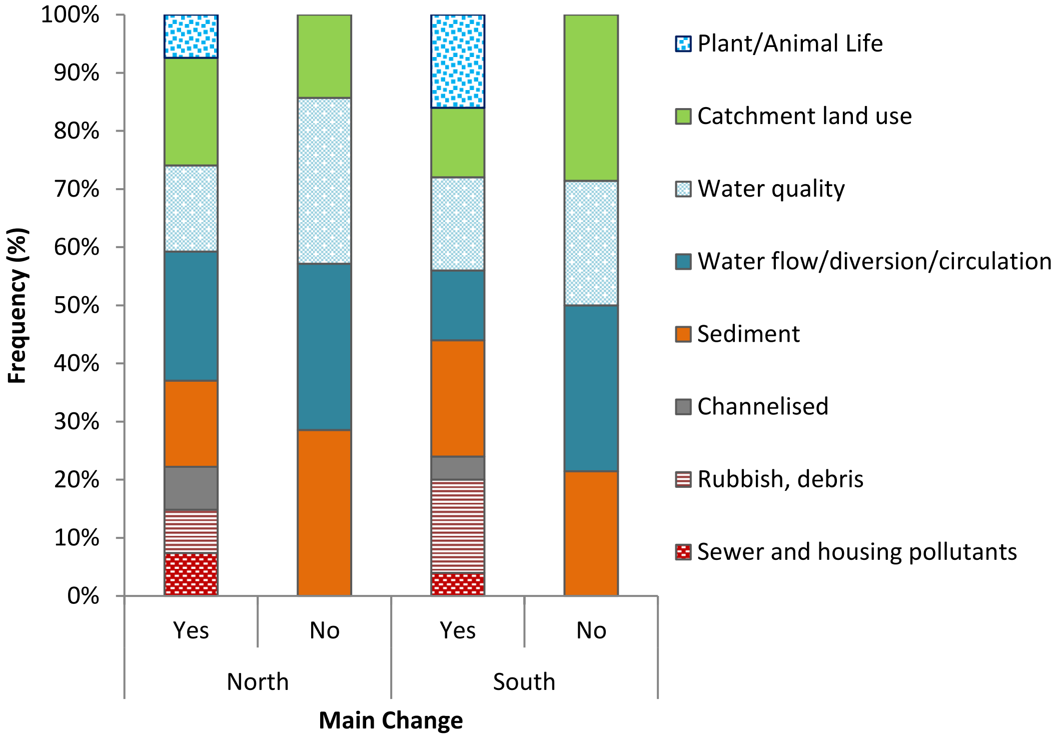


Figure 3.10. Frequency of agreement/disagreement of perceived main changes occurring over time according to participants in the north and south sectors of Kāne`ohe Bay (n=21).

Landscape evaluation with GIS and mapping

The 1978 and 2005 land-use land-cover (LU/LC) maps and conventional maps (1943, 1983, and 1998) compliment the landscape changes listed by interviewees above. In both 1978 and 2005, the LDI index increased along the north to south watersheds, except for Waikāne, which was lower than all ahupua`a (Table 3.8). The lower LDI at Waikāne is due to the largely evergreen and scrub shrub LU/LC (Figure 3.6-3.7). Additionally, these LDI index scores were lower within the 2005 layer compared to 1978, except Kāwā in the south. Kāwā was the smallest watershed with a high area of impervious surface and developed residential area (highest LDI coefficients 8.35 and 5.09 respectively) (Figure 3.6-3.7). The difference in LDI score could be attributed to the differentiation in LU/LC classification between 1978 and 2005, because of the improved detail by the latter year. For example, in 1978 the loko i`a and certain natural areas in Hakipu`u, along with wetlands in Waikāne and He`eia, were defined as cultivation land with a LDI coefficient score of 3.91 (Figure 3.6). Whereas in 2005, the Hakipu`u loko i`a and 'natural area' landscapes were classified as open water and evergreen respectively, both with lower a LDI coefficient of 1.00 (Figure 3.7). The wetlands in Waikāne and He`eia were also reclassified as palustrine emergent wetlands with a lower LDI coefficient of 1.26.

The 2005 landscape analysis of all ahupua`a, including non-shellfish study sites (Table 3.9), showed a general increase going southwards, however, Kahalu`u had the highest LDI (7.95), followed by Kea`ahala (5.42), Pu`u Hawaiiloa (5.08) and Kāwā (4.30). Furthermore, the Kualoa LDI was slightly higher (2.46) than other northern ahupua`a sites, with lowest LDI at Waikāne (1.25). In comparison with the impervious surface area, Kea`ahala had the highest development (51.08%), followed by Pu`u Hawaiiloa (41.01%) and Kāwā (33%). Kahalu`u, He`eia, and Haiamoa, were similar in value (16.25%, 17.22%, and 16.75% respectively), and were lower than the southern-most sites. In the north, the Kualoa impervious surface area was also slightly higher (7.19%) than other northern ahupua`a sites, with lowest value at Waikāne (1.37%).

The evaluation of landscape between 1943 and 1983 convention maps showed many of the changes mentioned within interviews. For instances, the dialogue of diversion and decrease in water input in Waikāne and Waiāhole, were evident. Early indications of waterway diversion were evident with the Waiāhole Ditch tunnel along the Waiāhole Forest and a pipeline that crossed from Ko`olau Range to `Ewa side (Figure 3.8). By 1983, the Waiāhole Reservoir was developed and fed both the Waiāhole stream and `Ewa side of the Island (Figure 3.12). Streams in the upper mountain range that were initially mapped in 1943, were no longer illustrated, instead further tunnels were shown above the Waike`eke`e and Uwau Stream (upper Waikāne and Waiāhole ahupua`a).

Land-use changes in 1978 were agricultural, grazing, and rural residential in the north sector (Kualoa to mid-Kahalu`u) (Figure 3.11). In the central (lower-Kahalu`u) to southern sector these changes were grazing and agricultural land, mostly single family and apartment residential, with smaller areas of commercial and industrial areas (Kāne`ohe and Kāwā). Mōkapu Peninsula was designated a military zone on the 1978 map and maps after this period. In 1983, further classifications included lower intensity land use such as housing, schools, and golf areas (Figure 3.12). In 1943, multiple loko i`a present along the bay, including the three current loko i`a in this study, Moli`i, He`eia, and Waikalua were evident (in Hakipu`u, He`eia, and Kāwā ahupua`a, respectively). Additional loko i`a included one in Kualoa and Kahalu`u, two smaller loko i`a near Kahalu`u, and multiple loko i`a in the southeast portion (Figure 3.8). By 1983, two remained in Kāne`ohe and Kāwā ahupua`a, one was altered to a marina, and the following loko i`a - Oohope, Kalokohanahou, Punalu`u, Mikiola, Kapu`u, Mahinui, and three unnamed sites - became residential housing and roads (Figure 3.12).

This study investigated changes to loko i`a stream input over time. In 1943, Kāwā stream flowed into Waikalua loko i`a (Figure 3.8), but there no clear indication of input from Kāne`ohe stream. However, in 1978 it looked like Kāne`ohe stream also fed this loko i`a (Figure 3.11), while neither did so by 1983 (Figure 3.12). In 1943, the streams of Waihe`e and Kahalu`u with an additional channel fed Kahalu`u loko i`a (Figure 3.8). By 1978 these were diverted away from entering the loko i`a (Figure

3.9). The large loko i`a (including Nu`upia) on Mōkapu Peninsula looked unchanged between 1983 (Figure 3.12) and 1998 (not shown). These loko i`a were later listed as conservation land (Figure 3.7). The streams of He`eia and Hakipu`u travelled the same course over time, whereas, Waikāne stream shifted north between 1943 and 1983 (Figure 3.8 and Figure 3.12). In 2005, the He`eia stream travels along the He`eia loko i`a side (Figure 3.7) and enters via mākāhā (sluice gate of fishpond; Personal observation 2014). Whereas Hakipu`u does not enter Moli`i Pond, and neither does Kāne`ohe or Kāwā streams enter Waikalua loko i`a (Figure 3.7).

Table 3.8. The 1978 and 2005 Land Development Intensity index (LDI) score of each study ahupua`a.

Ahupua`a	1978 LDI	2005 LDI
Hakipu`u	2.21	1.67
Waikāne	1.56	1.25
He'eia	2.97	2.54
Kāne'ohe	3.55	3.08
Kāwā	4.16	4.30

Table 3.9. The 2005 impervious surface area (in km and percentage), and the Land Development Intensity index (LDI) score with standard deviation for the ahupua`a and associated shellfish site in Kāne`ohe Bay.

Ahupua`a	Shellfish Sites	Imp. Surf. (km²)	Imp. Surf. (%)	LDI	LDI s.d.
Kualoa		0.17	7.19	2.46	0.29
Hakipu`u	Moli'i Loko I`a	0.13	2.38	1.67	0.15
Waikāne	Waikāne Pier	0.09	1.37	1.25	0.21
Waianu		0.08	3.00	1.65	0.20
Waiāhole		0.17	1.68	1.35	0.20
Ka`alaea		0.24	5.29	1.86	0.20
Haiamoa		0.28	16.75	3.24	0.43
Waihe`e		0.32	5.38	1.80	0.22
Kahalu`u		1.86	16.25	7.95	1.10
He`eia	He`eia State Park	1.98	17.22	2.54	0.39
	He'eia Loko I`a				
	He`eia				
He`eia/Kea`ahala	Lilipuna Pier	1.59	51.08	5.42	1.45
	Moku o Lo'e				
Kāne`ohe	Kāne'ohe Pier	2.92	19.79	3.08	0.50
	Kāne`ohe Beach Park				
Kaneohe & Kāwā	Waikalua	2.36	26.54	3.69	0.69
	Waikalua Loko I`a				
Kāwā	YWCA Pier	1.80	33.00	4.30	0.87
	YWCA				
Pu`u Hawaiiloa		3.87	41.01	5.08	0.95

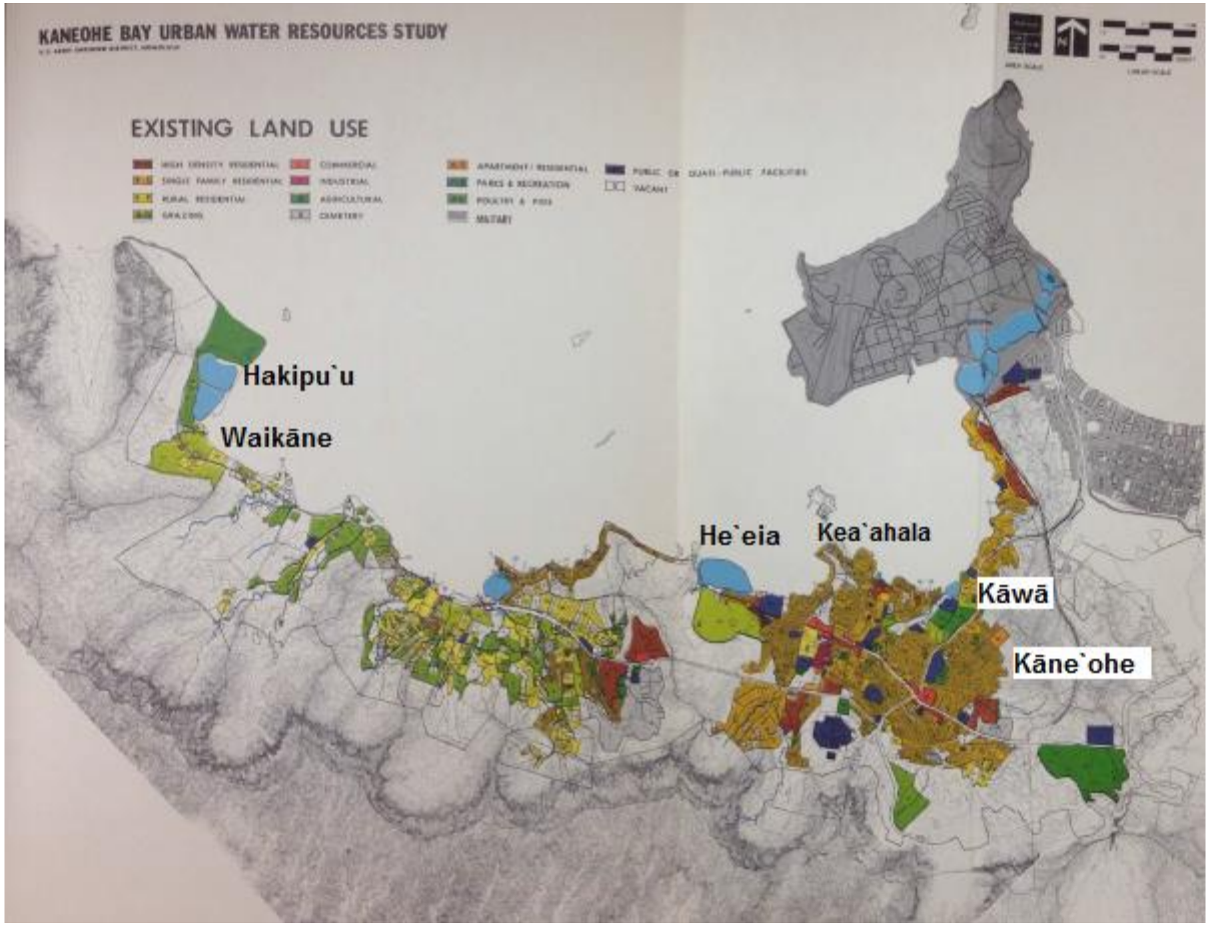


Figure 3.11. The 1978 classified land use in Kāne`ohe Bay (USAEC 1978) , and the study ahupua`a (Hakipu`u, Waikāne, He`eia, Kea`ahala Kāne`ohe, and Kāwā)

The main land use included residential land use (high density: A-H red, single family: R-S light orange, apartment/residential: A-R dark orange, and rural housing: R-R yellow), grazing (A-G lime), agricultural (A green), commercial and industry (C and I pink and violet), and military (dark grey).

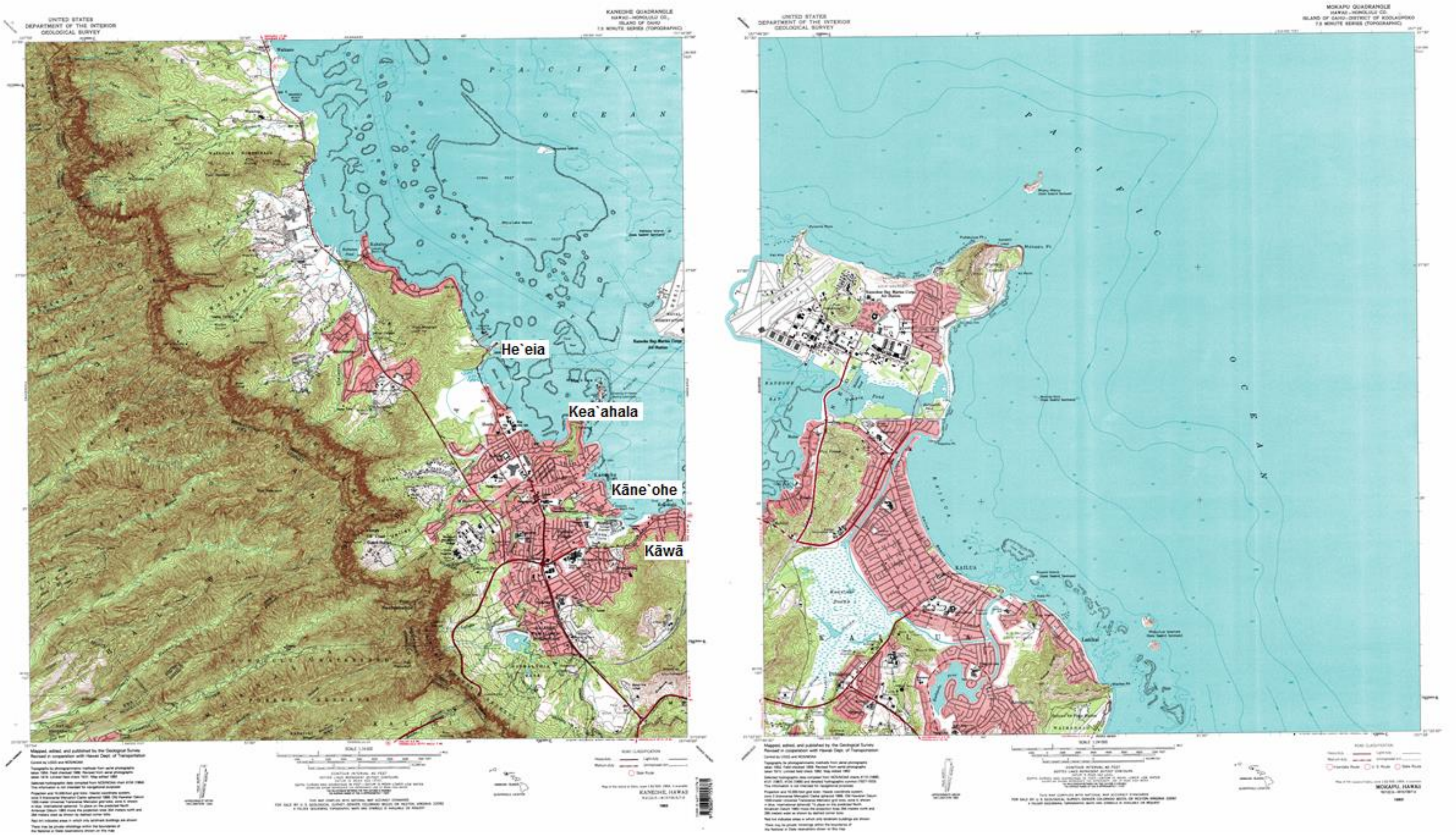


Figure 3.12. The 1983 conventional maps of Kāne`ohe Bay (USGS 1983), and the study ahupua`a (He`eia, Kea`ahala Kāne`ohe, and Kāwā).

3.3.5. Environmental condition and indicators

Participants were asked for their perceived score (poor to excellent) of the environmental condition of the site and catchment (Table 3.13a-d). The score showed that participants in the southern sector perceived their respective site and catchment higher than participants in the northern sector (Figure 3.13a and b). Participants with less experience (<10 to 20 years) scored the site and catchment slightly higher than more experienced participants (20-30 years; Figure 3.13c and d). Site and catchment scores were not statistically different between locations ($v^2=0.016$, DF=1.0, $p>0.05$; $v^2=0.20$, DF=1.0, $p>0.05$, respectively) or participant experience ($v^2=1.68$, DF=1.0, $p>0.05$; $v^2=0.22$, DF=1.0, $p>0.05$, respectively).

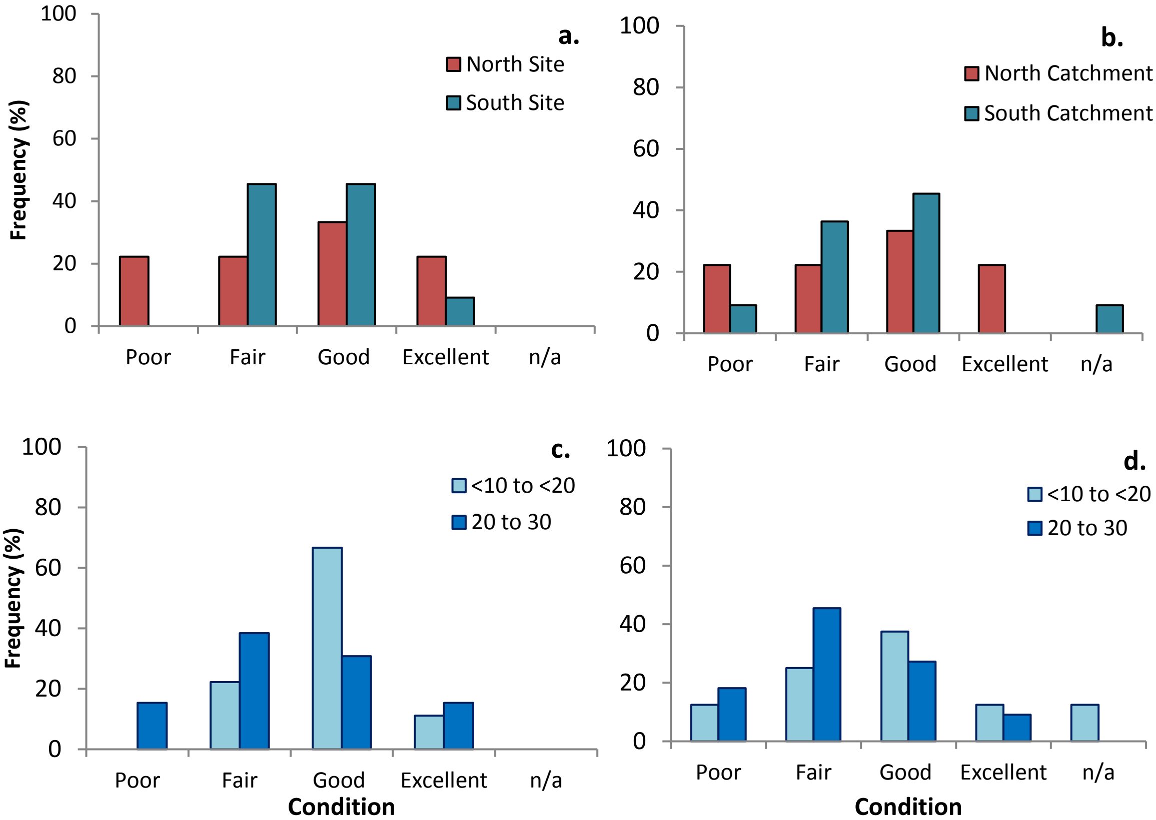


Figure 3.13. The score frequency of environment condition (poor to excellent) according to participants (n=21) of the north and south (a) sites, and (b) catchments; and participant experience (<10-20 and 20-30 years) for (c) sites, and (d) catchment.

The qualitative descriptions that accompanied the above site scores are as follows. A poor and fair score was associated with the perceived decline in aquatic life and size, an increase in introduced species, landscape development, changes in mud and sand, and declined state of the environment (Table 3.10). A good score was associated with improved water clarity, in coral growth, less run off, healthy aquatic life and less invasive species. There was no description given for an excellent score. The qualitative descriptions that accompanied the above catchment scores are as follows. The poor and fair site scores were associated with channel erosion, declined water clarity, relocation of fishing area, water diversion, landscape management practices and sediment run-off, and the lo`i kalo that are not yet functioning (Table 3.10-3.11). Good scores were associated with lo`i kalo, decreased sediment, development, river input for brackish environment and aquatic fishery, improved land uses with Best Management Practices (BMPs) in place. Excellent scores were associated with the catchment being well-stewarded and minimal development.

Participants also provided good and poor environmental indicators that they utilised for their site activities (e.g. fishing; Figure 3.14), and these overlapped with the descriptive dialogue (Table 3.10-3.11). In the northern sector, the most frequent good indicators included aquatic life and behaviour of animals, biodiversity, and water quality/clarity/smell; and the main poor indicators were sediment (mud/silt), the channelisation of streams, and runoff. In the southern sector, the main good indicators were water quality/clarity/smell, weather indicators (e.g. rainy weather was associated with run-off), and water condition; and the main poor indicators were water quality/clarity/smell, sediment state, and sewer/waste/rubbish. An example of sediment as a poor indicator was that runoff was negatively associated with healthy limu.

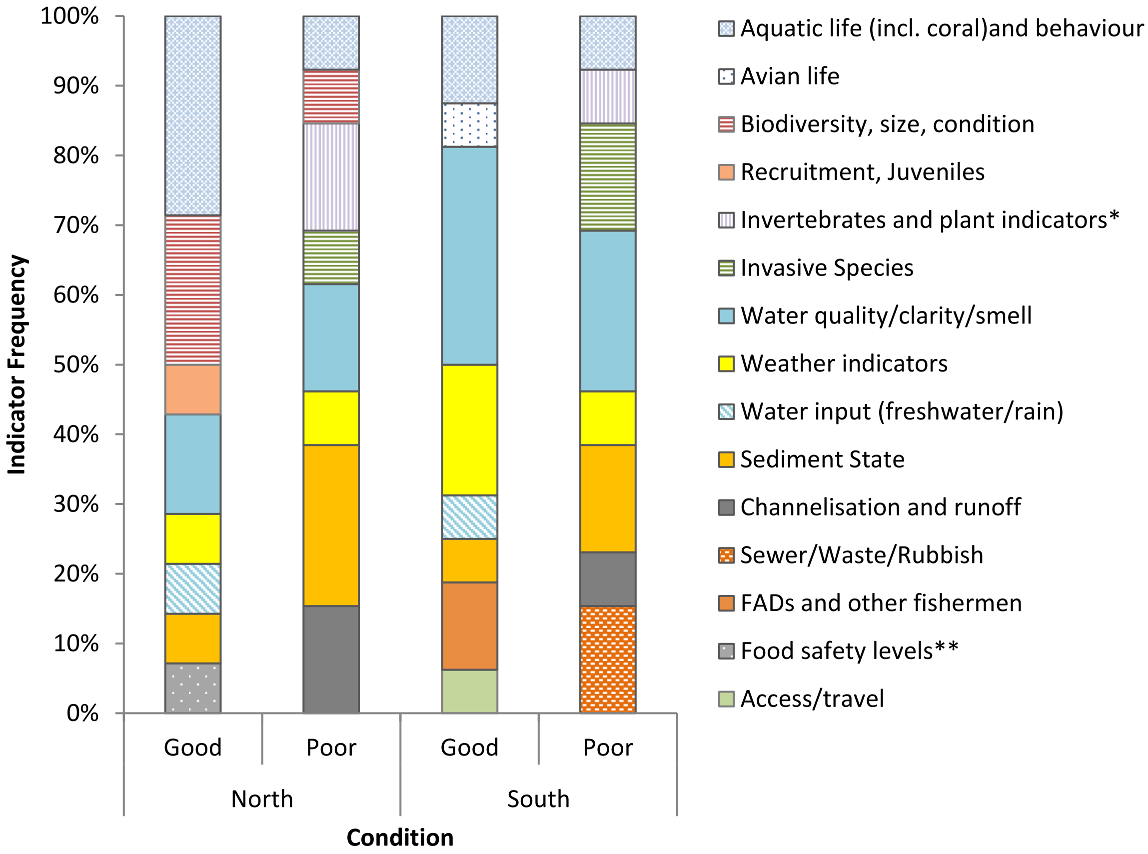


Figure 3.14. The environment indicators (good and poor) that influenced site activities in the north and south according to participants (n=21). ****Distyospheeria cavernosa*, **sea cucumbers, red worms, **microbiological guidelines.

Table 3.10. The qualitative description of site condition associated with the quantitative scores by Local Practitioners and Specialists (LPS) and Recreational Participants (RP) (Figure 3.14).

Examples of site condition descriptions	
Poor	Drastic **decline of animals**, stopped fishing, some **do not reach large enough sizes**. **Fishing** location shifted outside the bay (LPS). The channel **used to be lively with fish and crabs**. Now there isn't anything, **invasive algae** taken over (RP)
Fair	**Urban/residential development** (LPS); Big changes in **mud and sand** (LPS). **Improved**, in 1980s it was worse, it used to smell (RP)
Good	**Improved – water** is clearer and cleaner, but **no animals**. In the past big foam all over the beach (LPS) Two scores: Good at pier for **fishing** (RP); Greatly **improved** in 10-12 years in the bay, especially **coral growth** in the south end (RP); Dredging during WWII **a lot cleaner and less run off** compared to 20 years ago (RP); **Healthy marine life, minimise invasive species** (RP) Fishpond value **improved** condition and **mangrove removal** in last 20 years (RP)
Excellent	No description given

Table 3.11. The qualitative description of catchment condition associated with the quantitative scores by Local Practitioners and Specialists (LPS) and Recreational Participants (RP) (Figure 3.14).

Examples of catchment condition descriptions	
Poor	**Erosion of channel** becoming shallower (RP)
Fair	Decreased water clarity used to see 20 feet down. Shifted fishing and boating activity, from the south to north sector (LPS); Opae (shrimp) **ecosystem has declined** (LPS) Sail in the south and **fished/dived in the north** (RP) Water supposed to come from Mauka (inland), [but] diverted to other side, affects ecosystem (RP); Restoring this area, the **watershed health** is fair (RP) **Land use: residential, storm run-off, and lo`i** not yet functional yet (RP)
Good	It has changed, more development, **still a little country such as agricultural, lo`i no longer active**. The lo'i system settles soil back in the land, so the loss of these has caused an **increase in silt and mud**, which kills the coral reef in the bay (LPS) River flow from the mountain is good for fishing. It brings down opae [shrimp] and bait fish, and especially pāpio, guppies, and river fish (LPS) **Water input in canal from mountain**, natural brackish water (RP) Pollution was evident in 80-90s, now **improved community and land use**. Construction sites regulated now with **Best Management Practices** (BMPs) (RP)
Excellent	**Well stewarded and minimal urban development** (LPS)

3.3.6. Management and practices

The management and practices of participants involved in tourism and non-fishing related activities included tourism boat permits regulated by DLNR (9.5%). According to participants who fished or harvested, inclusive of loko i`a (95%), practices and management were based the best time to fish relating to environmental cues, seasonal cues (fishery life cycle, moon cycle), and the State fishery regulations. Participants provided the following State regulations (91%): there are seasonal restrictions for particular species (30%), size limits (40%), catch limits (15%), limu specifications (10%), no regulation for offshore larger fish (such as ma`ima`i and tuna) (5%), fishing methods restrictions (cast/throw nets) (20%), and general rules and regulations (20%). Further activities included restocking of fisheries by the State (10%), including pāpio and grey striped mullet, and restocking loko i`a with native herbivores (10%). In addition to this, also mentioned were specific rules and regulations applied at He`eia Kea Wharf, and loko i`a, that are managed privately.

Over half of the participants (57%) agreed that management was effective, some disagreed (19%), and others said it was partially effective (24%). Generally, the fishery regulations were effective (29%), however, current issues included the enforcement and policing of regulations (43%), breaking of rules including illegal net uses (14%), and invasive species are problems to native fishery (e.g., Australian mullet vs. native mullet) (9.5%). Loko i`a fishery protocols were effectively managed because they were private property, and fishing was kapu/prohibited (9.5%). Management of the aquatic areas, such as loko i`a and the inner bay, are either affected or benefit by the surrounding watershed uses and water quality (9.5%). The inner bay has improved as a result from land-to-sea management (9.5%). In addition, the limit of tourism boat and business operating limits managed less pressure on fishery in the bay (9.5%).

Better management was framed within the principles of mauka makai, local based knowledge, and both individual and community responsibility (Table 3.12). Freshwater systems were essential sources of life to the bay, impacted by diversion, poor land use practices, and whole system perspective (see Mauka Makai in Table 3.12). Traditional management systems lend themselves towards key ecological system principles that can better inform management practices today. Interviewees suggested the following aspects towards improving overall management: community cohesiveness, accountability, mālama (to take care of, tend, protect or preserve) the area, and place-based ecological regulations.

Table 3.12. Examples of key paraphrases used to describe various fisheries management by Local Practitioners and Specialists (LPS) and Recreational Participants (RP) in Kāne`ohe Bay. Specific monthly details were kept confidential.

Key management themes and examples of key paraphrases
Mauka Makai
Prior to **water diversion** from Waiāhole to the other side of the Island, there were many big freshwater schools of fish. This impacts Waiāhole and Waikāne area (Note: Both Waiāhole and Waikāne connect with the same stream mouth input to the bay). **So, recruitment of mullet has not recovered, it has declined** more and more (LPS); Management by the Department of Land and Natural Resources (DLNR) is not effective - understaffed, **so cannot manage water and land properly**. **Better land management and fishing practices is required**. The **government and community** need to change and take care of the **whole system**. By working up stream, it would correct downstream land management, and people that utilise water and Lo`i system would lead towards best management practices. The **bay needs from freshwater source** (LPS). Hawaii Islands is so big when you consider the water environment. Management **regulations are not effective, as there is not enough policing**. At this Park netting is illegal removed several nets, **we try to help police and manage** (30 years RP). The **fishpond restoration and management is effective**. However, overall **management is ineffective** because of the input and impacts from the **surrounding environment (**residential **non-point source of pollution**, **roads, and storm drains)** (>10 years RP) The bay **requires increased integrated interaction across watersheds**. Hawaiian organisations are using **traditional management to improve waterway health**, by creating more **wetland systems, awareness and education, and improved watershed ecology**. Lo'i kalo is essential to overall health of wetlands. If all streams are diverted to these systems, phytoremediation can occur before streams enter in bay (20 years RP)
Local values and practices
"The socio-political ahupua`a system has been dismantled, but all the land area is still based on the ahupua'a" (LPS)
Traditionally, **Konohiki regulation was place-based knowledge,** distinct to each island. E.g., mullet have different seasonal migrating and spawning periods across the islands. This would **improve current regulation along with enforcement** (LPS) There is a lack of **response and enforcement** and open access. Traditionally, Konohiki managed the fisheries, **and people mālama the area** (LPS). **There are no people to enforce it**. There is **open access** for gathering rights, which also **means free of responsibility**, which is an introduced American system. Traditionally fishing was by those from the area, and community policed. This does not work when you are from elsewhere than the bay. **There should be support for stronger communities, subsistence, and not commercial**. Commercial and aquaculture facilities do not pay for anything, only licence **There needs to be policing, regulation, and enforcement.** We contact people locally (LPS)

3.3.7. Correlation analyses

A correlation analysis investigated the association between socio-cultural indicators, participant experience, and landscape indices. Correlation between both landscape indices, the Land Development Intensity (LDI) index (Table 3.13) and impervious surface (percentage), produced the same association strength and significance. Therefore, the latter is not presented in this section. The perceived main changes scores (low to high impact score: 1-4) positively correlated with the LDI (low-high development: 1-10; r=0.54, p<0.05). The catchment score (poor-excellent: 1-4) had a significant negative correlation with the LDI (r= -0.47, p<0.05). There were no other significant correlations with landscape indices. The association between perceived species abundance and environmental scores were also significant for he`e/octopus, pacific oyster, and introduced pāpa’i/crab (no table). He`e abundance was positively correlated with the environmental indicators score (ordered by increasing positive condition; r=0.89, p<0.05), and negatively correlated with the catchment score (1-4: poor to excellent; r= -0.97, p<0.01). The perceived abundance of the pacific oyster correlated positively with environmental indicator score (r=0.97, p<0.01), and negatively with the main changes score (the latter score increased with negative impacts 1-4: good to poor; r =-0.95, p<0.05). The introduced pāpa`i negatively correlated with fisher experience, which was illustrated earlier for the natural resource analyses (Table 3.6).

Table 3.13. Correlation between the Landscape Development Intensity index (LDI) with socio-cultural indices, as corrected by the Benjamini-Hochberg critical value (i/m*Q) (m=23, Q=0.05). Given is the correlation coefficient (r), p-value, with significant values in bold.

	LDI	
Variables	r	p-value
Main changes score*	**0.54**	**0.03**
Catchment score	**-0.47**	**0.04**
Oysters	-0.75	0.09
Enviro. index score**	-0.35	0.11
Participant experience	0.23	0.32
Omaka	-0.87	0.33
Site Score	-0.22	0.34
Invasive limu	-0.54	0.46
Native limu	-0.37	0.47
Introduced crab	0.34	0.57
He`e/octopus	0.30	0.63
Ula/crayfish	0.27	0.73
'Anae/mullet	0.18	0.78
Pāpio	0.00	0.99

*Main changes score is the total negative change score.
**Environmental index score: is the total positive condition score.

3.4. Discussion

Due to their position, estuarine environments are vulnerable to anthropogenic alterations and interactions, O`ahu is no exception. Kāne`ohe Bay is a dynamic ecosystem, inhabited by a diverse array of wildlife, a place of sustenance, tourism, and well-being for the local community. The indigenous paradigm, such as the notion of reciprocity and to “consult nature” (Devaney et al. 1982, Poepoe et al. 2003, Berkes 2012), is missing from ecological resource management practices (Berkes 2012). In Hawai`i, the role of indigenous ecological knowledge, values, and methodology are increasing within contemporary natural resources management (Poepoe et al. 2003, Aswani and Hamilton 2004, Drew 2005, Jokiel et al. 2010, Hufana 2014), and ecological assessments (Kawelo 2008, Ratana 2014). The focus of this discussion is the key themes and findings of the socio-cultural indicators, landscape indices, and management practices. Interwoven throughout this discussion, are the underlying protocols, values, and ethics held by local people within Kāne`ohe Bay.

In historic times Kāne`ohe Bay and its surrounding area became one of the primary Hawaiian population centres on O`ahu Island (Kelly 1976). The importance of place to participants were most noticeable by Kānaka Maoli, their cultural affiliation was to their familial ahupua`a. According to a long-term local resident within the bay, people identified with the ahupua`a, and were once the socio-political economical unit of the traditional system. Thus, the ahupua`a, is an important affiliation by long-term Kānaka Maoli and non-Kānaka local residents of the bay. Recreational non-Kānaka differed in their response, usually without an answer. This sense of place, conveyed by the older Hawaiian generation was a much more traditional nature, that spoke of specific location or land unit within an ahupua`a (an `ili: smaller than an ahupua`a and moku), compared to today’s generation where few would refer to ahupua`a, and most would identify to island-based location (Beamer 2005). For Indigenous People the processes such as identity formation and knowledge production are derived from the land or place (Calderbank and Macer 2008). Land operates as a primary reference point from which knowledge and behaviour derive, because Native Hawaiians recognises `āina as “that which feeds”, “land is more than physical space, it is an idea that engages knowledge and contextualises knowing” (Meyer 2008). A common point of these ecosystems is that the term, ahupua`a, refers to an intimate association of a group of people with land, reef, and lagoon, and all that grows on or in them (Berkes et al. 1998).

Defining cultural and recreational values, or traditional and local knowledge, as separate concepts reduces the broader nature of people’s interactions. Cultural uses and values were interconnected with recreation, family-based activities, traditional systems such as loko i`a, and water-based activities such as to paddle va`a (outrigger canoe). For example, family activities included trans-generational observations (e.g. changes in shellfish activities), traditional stories and proverbs (i.e. cultural and traditional affiliation to place). Interaction of local Kānaka within the environment, followed the protocol of mālama `āina, of guidance from kupuna (elders, ancestors), and pule to the `aumakua and akua (pray, incantation, to the family deified ancestors or guardians, and to gods or deity) (Personal observation, communication, and interviews, 2014). For example, kupuna guided the restoration of traditional systems such as lo`i kalo (personal communications 2014). Local ecological knowledge, experiences, and practices within a local ecosystem are captured through time in social-ecological memory (Barthel et al. 2010). It is the duty of Hawaiians to mālama `āina, and as a result of this proper behaviour, the `āina will mālama Hawaiians (Kame'eleihiwa 1992). Mālama `āina is to protect and care for the environment (Friedlander et al 2000). Furthermore, it is done with the notion of a familial relationship with `āina (Kame'eleihiwa 1992).

When locals are interacting with the environment, rather than say 'go fishing', they instead "…go holoholo [to go out for pleasure, stroll, promenade], this is to cruise, because the fish have ears". To go holoholo extended into the cultural manner and unspoken rules of respecting the ocean. This is found within the Hawaiian proverb of "*He pepeiao ko ka i`a, the fish have ears*" (Pukui 1983). Within a narrative, going out quietly, and doing so meant selecting only what was needed (I: interviewer, P: participant). "*Hāmau ka leo* [Silence; hush; be still]. *You couldn't talk when you go" (I) "And it's true. Even when tūtū went out, even to go fishing, a`ole* [nothing]. *Hāmau. And that's how you see it coming up, it's quiet. And it makes sense. You make big noise; [they are] all going to disappear. This way [quiet] they're all coming out, and you choose" (P). "So you take the one you need and leave the rest." (I). "Yes"(P)* (Maly and Maly 2012).

3.4.1. Favoured and targeted aquatic life

A diverse number of aquatic species fished, gathered, cultured, were observed by fishers across the bay. Both Local Practitioners and Specialists (LPS) and Recreational Participants (RP) included a diverse composition of local and O`ahu based residence, thus providing a range of aquatic species of importance within the bay. The most frequently mentioned fishery groups were i`a (fish in general), introduced plants – mainly limu (seaweed/algae), and the jacks and pompanos group (Section 3.3.3). Favoured fish species were consistent with those reported in recreational fisher trends in Hawai`i (NOAA 2015). In this current study, the goatfish species (weke, `oama, and kūmū), bluefin trevally (omilu of the jack and pompanos family), and mackerel scad (`opelu) – were favoured resources, that were also reported within the commonly caught non-bait species (NOAA 2015).

Overall, the LPS in the northern sector named a higher diversity of caught species than RP in both sectors. Compared to less experienced RP, the LPS and more experienced RP named a wider range of activities, fishing methods, and habitats. In Haena, on Kaua`i Island, local community members had different knowledge of their local fishery system to tourist (Vaughan and Ardoin 2014). The two groups rarely interacted with each other, they visited different areas of the coast, at different times, for different activities (Vaughan and Ardoin 2014). In addition, local residents were concerned that tourist activities affected certain fish species that only feed in particular places on particular tides (Vaughan and Ardoin 2014).

The mixed-methodology results indicated fishery declines that were not always accounted for in the quantitative questions of fishery abundances and changes over time. The differences between fisher experience also highlighted shifting baseline syndrome (SBS) (Pauly 1995). Both the LPS and more experienced RP Kānaka Maoli (Indigenous Hawaiian) interviewees reported higher declines in native aquatic life than less experienced participants (<20 years). An example of the change in native resources according to LPS is as follows:

"*Culturally important estuarine resources were gathered extensively along [the] shoreline and near the muliwai [estuary, stream mouth], but that list of species has diminished dramatically to the point where it's safe to say, except for a couple, resources are no longer present or available to gather*" (Pers. Comm. 2014).

More experienced fishers observed indicators of native fishery species decline in the bay. Interviewees shared that commercial harvesting nehu (Hawaiian anchovy, *Encrasicholina purpurea*) and lobster (crayfish spp.) ceased in the bay, a perceived indicator of decline. Today, *'spiny lobster is no longer available in the bay'* (Table 3.5). Historical documentation suggested lobster was a source of food for the ancient Hawaiians, and continued in the late 1970s, being a much sought-after catch for local fishermen and divers (Titcomb et al. 1978). Depletion of native species invertebrates was apparent in local markets with native forms too scarce for commercial harvesting (Titcomb et al. 1978). Spiny lobsters, *Panulirus* (ula) were rare in the bay, and more were noted in the northern part of the bay; their distribution was assumed to probably be fisherman-dependent (Chave 1973a).

Frameworks that maximise the use of earlier baseline knowledge would help to understand and evaluate the true social and ecological costs of fisheries (Pauly 1995). However, a problem with shifting baselines, is that we are left without a clear understanding of how fishery ecosystems functioned in the absence of major human impacts, and, the relative importance of syndergies among the factors driving decline (Knowlton and Jackson 2008). Furthermore, indicators of fishery biomass and structure variation should include human population size, activities, and accounting for SBS. Accounting for local fishery activity is important, especially considering that marine recreational fishers in Hawai`i took almost 1.4 million trips and caught nearly 4.2 million fish in 2014 (NOAA 2015). Among Pacific islands patterns of declined fishery have been related to human population size, or reserve status, especially noticeable on the main Hawaiian Islands (Knowlton and Jackson 2008). =
Mixed methodology was an important source of information relating to physical environmental characteristics, causes of fishery observations, and consequences of environmental changes. According to local Kānaka, the perceived abundance of native limu has been depleted, or occurs very

sparse. Reasons for the decline included degraded environmental conditions (i.e. runoff impacts), incorrect harvesting practices, and over-harvesting. A study along the main Hawaiian Islands implied that where significant habitat or environmental degradation occurs around heavily population locations, it is likely that this exacerbates the already severe impacts of intensive fishing (Williams et al. 2008). The most sought after seaweeds for food in the Hawaiian Islands is limu manueaua, *Gracilaria coronopifolia*, and limu kohu, *Asparagopsis taxiformis* (UH 2015). In the past, *G. coronopifolia* was commonly distributed, but has been seriously overharvested (UH 2015). A law passed in 1988 prohibited the collection of plants with “dark bumps” or cystoca (referred to by participants in this study) denoting a fertile, reproductive plant (UH 2015). *G. tikvahiae* was introduced to Hawai`i in 1987 to relieve the dwindling availability of native limu, and has the potential to be an invasive species on Hawaiian reefs (UH 2015). The invasive *G. salicornia* is now dominant in many regions of the native limu manueaua habitat (UH 2015).

In general, the reported perceived abundances of oysters decreased in the bay, but aLPS within the northern loko i`a reported increased abundances due to aquaculture. The management of the pond was by traditional mechanics, using the mākāhā (sluice gate), and tidal knowledge. This reportedly improved water circulation between the pond and the bay, and within the large pond, over the last year. The area of the wall is approximately 1,220 m in length (Apple and Kikuchi 1975), and the mākāhā was the most important tool for stocking and harvesting fishponds, and managing the water flux (Sato and Lee 2007). Due to declined national oyster production in the past, it was predicted that an increasing dependence on improved management and mariculture technique in order to booster production (Uyemura 1976). The culturing of shellfish species within the ponds of the bay were trialled over time. This included the Manila clam (*Tapes semidecussata*; synonymously called *Tapes philippinarum*), Sydney rock oyster (*Crassostrea commercialis*), Eastern oyster (*C. virginica*), and Pacific oyster (*C. gigas*) (Brick 1970, Pryor 1974, Uyemura 1976, Haws et al. 2014). The role of the mākāhā, the knowledge of the kia`i loko, monitoring tidal patterns, and managing water flow, were critical to the pond’s productivity (Sato and Lee 2007). Moli`i Fishpond was the only loko i`a in Hawai`i that has been continually in operation for over 600 years (Sato and Lee 2007). Classified shellfish-growing water areas for shellfish operations included two areas, Hilo on Hawai`i Nui, and Moli`i Fishpond on O`ahu Island (Department of Health 2013b).

3.4.2. Landscape evaluation by participants and GIS

Kāne`ohe Bay has been researched for its natural to urbanised gradient along the north to southern sector (Hunter et al. 1995). The landscape development has been measured and correlated to determine the difference in landscape gradient to socio-cultural indicators (current chapter) and inner bay shellfisheries (Chapter 4). The landscape gradient did not evenly increase from north to south. In agreement with interviews, certain ahupua`a within the north and south sectors, had higher impervious surfaces and channelised streams (Table 3.9, Section 3.4). The past conventional maps complimented the GIS-based 1978 land use land cover analysis, by providing the landscape and inner bay detail, not yet available within GIS data. The changes over time were consistent with interviews, including the loss of multiple loko i`a to residential development, waterway diversion, stream alteration/channelisation, and a military base.

Historically, muliwai/estuaries were zoned with kaha wai/freshwater ecosystems and streams of the land-and-sea systems, (Mueller-Dombois 2007), that is, they were managed as receiving bodies of freshwater systems. Within the present study, stream channelisation was a concern to participants, and impacted traditional management of mauka makai. The perceived consequences most likely impacted the estuarine environment and water flow. With the completion of the Waiahole Ditch Tunnel systems, most of the windward water above 500 foot elevation were diverted to leeward O`ahu (Office of State Planning 1992). These diversions of water had significant effects, springs dried up in Waiahole and Kahalu`u, and groundwater storage reduced, and stream input into the bay was reduced by over 40% (Office of State Planning 1992). The diversion of streams can affect the areas for spawning and juvenile fisheries (Lowe 1995).

Today three main loko i`a are in restoration or functioning along the bay, Moli`i pond, He`eia loko i`a, and Waikalua loko i`a (Personal observations). By the end of the 18$^{th}$ Century more than 300 loko i`a were conspicuously owned by the high chiefs (Apple and Kikuchi 1975). Within an evaluation of remaining loko i`a, 13 royal fishpond remnants in O`ahu met the criteria outlined by the National Register of Historic Places. Five of these were within Kāne`ohe Bay (Apple and Kikuchi 1975) and an additional eight were mentioned on Mōkapu Peninsula (Office of State Planning 1992). These were Koholālele, Mōli`i, He`eia`uli, Kanohuluiwi, and Waikalua (Apple and Kikuchi 1975) and Nu`upia (four fishponds), Halekou, Kaluapuhi, Heleloa, and Pa`akai (Office of State Planning 1992).

In the present study, socio-cultural indicators across environmental scales (fishery, site, and catchment) were interrelated. The environmental condition of the catchment positively correlated to the site. Although the LDI was unknown to interviewees when they quantified environmental condition, the score correlated with main changes (impact to the environment). This suggests that the participants' experiences of main environmental changes were sensitive to a measure of participant's view of land development. The perceived changes were significantly different between participant groups (RP and LPS). More experienced fisheries noticed reductions in relative abundance. This was significantly so for the introduced pāpa`i. Furthermore, the perceived abundance of he`e and oysters had contrasting correlations with environmental scores. Oyster abundance correlated with perceived main change impacts, while he`e did not. However, he`e were only mentioned by more experienced fishers (>20 years), who generally caught he`e along reefs, not necessarily near the land catchment. An earlier study on *C. gigas* found elevated contaminants near urbanised stream mouths, compared to other sites in the bay (Hunter et al. 1995). Small areal extent of live coral cover and low habitat complexity, particularly at deeper locations in the bay, are a result of anthropogenic impacts as well as habitat degradation associated with invasive algae (Friedlander et al. 2003). Wetlands within Hawai`i were at some point directly impacted by human land-use (Margriter et al. 2014). However, Margriter et al. (2014), found that correlations between the landscape indicators and other field indicators were not very strong (r ~0.50). These results suggest that further refinement of metrics is needed, including, the use of participatory GIS methods, which may provide a more accurate assessment across multiple scales.

In the present study, qualitative analysis of dialogue provided depth, as it reported the reasons behind impact and indicator scores. The most frequently mentioned main changes of impact were catchment land-use, sediment state, and water parameters (quality/clarity/smell). Interviewees expressed that fair and poor catchment condition scores were associated with catchment land-use and run-off, channel erosion, and were associated with sites that were good for leisure but not fishing. Poor and fair site condition scores were associated with urban and residential development, changes in sediment type, and affected aquatic life and behaviour (Figure 3.14, Table 3.10). The quantitative and qualitative evaluations of the environment were associated with the physical environment, human connections to place, and the consequences of human impacts. Similar with past survey studies in Hawai`i, recreational fishers were most concerned by the impacts of stream diversions, sediment and pollutant runoff from urbanisation and deforestation, and overfishing (Lowe 1995). Kāne`ohe Bay has been exposed to many anthropogenic pressures as mentioned within interviews as discussed in the following section.

3.4.3. Management and fishery protocols

Participants in the present study followed a combination of the State regulations and rules within fisheries, best management practices in the catchment, fishpond management, and more local conservative practices. The rules given by participants agreed with those held by the State. Fisheries regulations included catch limits (pāpio was 10 per day), and certain sizes (squid/he`e, pāpio, mullet, and moi), seasonal closed/kapu periods (lobsters were closed May-July, moi closed June-August, and `ama`ama (young striped mullet) closed December-March), permanent prohibition of shellfish, and prohibited fishing from marine reserve areas elsewhere on the island (DAR 2015a). Further regulated areas, such as He`eia Kea Wharf (Kāne`ohe Bay), HIMB, specific rules and regulations at He`eia Hawai`i Marine Laboratory Refuge (Moku o Lo`e), and closed areas within Kāne`ohe Bay are provided (DAR 2015a).

Certain fishing protocols used by long-term RP and LPS Kānaka were more conservative than conventional management regulations. According to these fishers, changes in equipment type, catch per unit effort, species-habitat presence, suggested changes to the fishery itself. The LPS individuals had stopped fishing altogether or gathering certain native species they feared had severely declined. The link between species-habitat shifts, such as the decreased abundance of he`e or native limu in their niche, and their replacement by invasive species are important local system knowledge. It is supported that environmentally engaged participant groups can provided detailed knowledge (Schultz et al. 2007). This includes long-term monitoring of particular species, habitats and ecological dynamics (Schultz et al. 2007). This knowledge and further engagement with local bodies of long-term Kānaka would benefit both the cultural-important species and habitat, the goals of State of Hawai`i Aquatic Invasive Species (AIS) management plan (DLNR 2003), and would inform an important traditional component within the proposed National Estuarine Research Reserve[3]. Within the AIS plan, a particular strategy (Strategy 5G) is to integrate AIS education efforts into local cultural and ethnic community efforts; and specifically, to work with native Hawaiian groups and other community groups to emphases the threats that AIS pose to native species and traditional practices (DLNR 2003).

A range of predatory and introduced species were targeted in the bay and loko i`a, including to`au (*Lutjanus fulvus*), ta`ape (*L. kasmira*), kākū/barracuda (*Sphyraena barracuda*), invasive limu (*Gracilaria* spp.), and introduced crab (multiple species). Predator fish were said to impede the function of loko i`a, because their management relies on raising native herbivorous fish and shellfish. The impact of introduced species to Hawai`i, for examples the Samoan crab (*Scylla serrata*) and other species, have altered the composition of the shore fauna (Titcomb et al. 1978). Ta`ape, to`au, and roi (*Cephalopholis argus*, peacock grouper), were reported to affect the native lobsters' ecosystem. These two snappers were introduced to the Hawaiian Islands from Moorea in 1956, and feed principally on crabs and small fishes (Randall 2010). The young snappers may be found in brackish water (Randall 2010), making loko i`a especially ideal environments. According to the AIS document, contradicting reports between biological fishery researchers believe ta`ape and roi may have less impact than is thought by fishers and aquarium collectors, although further investigation is required (DLNR 2003).

Participants who had a longer association with the bay, and who were involved in local environmental groups, distinguished between improved and degraded conditions. This is most likely due to more experienced fishers interacting with the bay more frequently, and being present, or learning from the older generation who were present during urbanisation of the 1950s to 1970s (Department of Health 2013a). There is documented evidence of increased volcanic soil run-off into the streams in the rural lands of the north-sector in the bay, but more so in the urbanised south-sector, with significant

[3] See http://planning.hawaii.gov/czm/initiatives/nerrs-site-proposal-process/

sediment and freshwater run-off due to increased impervious surfaces (Jokiel 1991, Laws 2000). Increased reef erosion and increased runoff from land caused shoaling of the lagoon (between the barrier reef and the shore), which became shallower at an average of 1.6 metres (Roy 1970).

Multiple efforts in State policy and implemented programmes have focussed on Kāne`ohe Bay. The Hawai`i Office of State Planning (OSP) recognised that "a strong relationship exists between activities in the watershed and the health of the bay" (Office of State Planning 1992) and the need to coordinate management of all land and water areas across the State to protect its coastal resources (Office of State Planning 1996). The task force indicated that water and ecological quality in the bay had been deteriorating since the mid-1980s, and continued to do so (Office of State Planning 1992). In 1990, the U.S. Congress enacted the Coastal Zone Act Reauthorisation Amendments (CZAEA), modifying the Coastal Zone Management (CZM) Act of 1972. CZARA added a new Section 6217 "Protecting Coastal Waters" requiring states with CZM programs to develop and implement coastal nonpoint pollution programs to be approved by the federal National Oceanic and Atmospheric Administration (NOAA) and the Environmental Protection Agency (EPA) (Office of State Planning 1996). From this "best management practices" (BMPs) were established for land and water users that were site-specific and adaptive over time in combination with the development of EPA's management measures for sources of nonpoint pollution in coastal waters (Office of State Planning 1996). Kāne`ohe Bay has shown improvements in water quality over the past decade and today is somewhat stabilised, partly due to elimination of the main effluent discharges, however runoff from the numerous streams during winter storms conveys large quantities of silt and other material which settle into the bay (Department of Health 2013a).

In the present study, there was little consistency about the current effectiveness of management. Many agreed it was effective in the bay, and the responses to loko i`a agreed that management was effective because it was privately managed. Those who disagreed or had other views suggested that further improvements are needed at the local level, to improve regulations and policing, and to implement the overarching principles of mauka makai, traditional functioning, and place-based practices. One problem today is that the current land management system is divided into terrestrial and coastal ecosystems, with private land ownership and interagency jurisdiction (Smith and Pai 1992). There are multiple restoration or traditional maintenance efforts by groups and organisation along with State officials, across the bay. Both the LPS group and some of the RP mentioned either mauka makai, integrated function, to mālama the environment, and/or traditional management. Although some of the RP was non-Kānaka, the Kānaka Maoli based principles such as mauka makai and kapu were influential to management perceptions as highlighted within the qualitative analysis. The familial and spiritual connection to the land required that Kānaka Maoli seek pono (harmony) in their interactions with `āina (Beamer 2005). In addition, there needed to be improved community cohesion, community accountability, and less outer-bay pressures with fishers and tourism. Past research has shown that locations influenced by customary stewardship harboured fish biomass that was equal to or greater than that of no-take protected areas in the Main Hawaiian Island (Friedlander et al. 2003). In Kāne`ohe Bay specifically, the fish assemblage was distinct from all other fish assemblages around the state (Friedlander et al. 2003). Furthermore, the Department of Planning for Water Nonpoint Pollution required that community were involved as a necessary implementation tool (Office of State Planning 1996). The implementation of the present study can guide the Department of Planning towards the management needs by the local community.

3.4.4. Summary

Estuaries are among the most important environments of the coastal zones. They are biologically productive areas, providing for socio-cultural well-being, sustenance, and economic values. Estuaries also rank among the most heavily impacted aquatic ecosystems on earth, affected by a range of anthropogenic activity in adjoining coastal watersheds and in the water bodies themselves This is the first study to combine landscape indices, socio-cultural indicators and values (Chapter 3), and scientific ecological indicators across Kāne`ohe Bay (Chapter 4). The interviews particularly focussed on knowledge systems of estuarine resources and management from the perspective of Recreational Participants (RP) and Local Practitioners and Specialists (LPS) of Kānaka Maoli and non-Kānaka affiliation, who interact with the bay. Kāne`ohe Bay is a highly social, cultural, and ecologically valued system.

Kāne`ohe Bay has received multiple anthropogenic modifications and impacts, as documented within current interviews, previous research, and local agency environmental management documents. Within the present interviews, participants had provided key concerns for areas of intense development, which ranged from urban development, stream alteration, and water diversion. The GIS Landscape development intensity (LDI) and interviews indicated pockets of urban development along the bay, and indicated areas of higher impervious surfaces and channelisation. Conventional maps provide another further evidence of landscape changes that are not illustrated within previous GIS land-cover layers. The changes over time were consistent with interviews results. Participants who had a longer association with the bay, and who were involved in local environmental groups, distinguished between improved and degraded conditions. Furthermore, the correlation between participants' perceived environmental changes correlated with the GIS-based landscape values. Participants did not know the GIS scores. In addition, the perceived abundance of introduced Pacific oysters, but not native He`e, were positively correlated with perceived environmental scores. Landscape changes were further associated with site based ecosystem changes as discussed throughout the interviews.

Compared to short-term RP, long-term locals and LPS named a wider range of activities, fishing methods, target versus favoured fishery, and habitats. Both the LPS group and the long-term RP who were affiliated as Kānaka Māoli had reported higher declines in native aquatic life. Mixed-methodology results from the present study provided indicators of fishery declines that the quantitative scores had missed. The quantitative scores of perceived relative abundance were not considered effective enough to compare across interview participants.

In the present study, there was little consistency about the current effectiveness of management. Certain fishing protocols used by long-term RP and LPS Kānaka Māori were more conservative than conventional management regulations. Both LPS and some of the RP mentioned either mauka makai, integrated function, to mālama the environment, and/or traditional management. Although some of the RP were non-Kānaka, the influence and importance of Kānaka Māoli based principles such as local mauka makai and kapu were commonly recognised and practiced within this region.

Both the LPS and RP groups shared similar management principles. Many said the current fishery management (fishery regulations) were effective, those that disagreed referred to the ineffective nature of policing, to the need for community cohesion, and to better prevent the impacts of stressors to the bay. The environmental condition of the bay required improved on-land practices, as well as activities inner bay, to be guided within the principal of mauka makai. The knowledge system of Kanaka Maoli currently guide the restoring cultural-ecological systems (e.g. within the upper stream[4] to lo`i kalo[5] to loko i`a[6]), with support from State agencies[7] and the community. Socio-cultural indicators and values along with landscape indices can be used towards future assessment and monitoring of this estuarine environment. The following chapter investigates shellfish ecological metrics. These are tested for association with the landscape indices and socio-cultural values to inform management practices.

[4] Papahana Kualoa (http://www.papahanakuaola.com/)
[5] Traditional Hawaiian terraced taro ponds: Kāko`o `Ōiwi (http://kakoooiwi.org/)
[6] Traditional Hawaiian fishponds: Paepae o He`eia (http://paepaeoheeia.org/) and Waikalua (http://www.thepaf.org/waikalualokofishpond/)
[7] He`eia ahupua`a is a National Oceanic and Atmospheric Administration Sentinel Site (http://oceanservice.noaa.gov/sentinelsites/hawaii.html) and a proposed National Estuarine Research Reserve (http://planning.hawaii.gov/czm/initiatives/nerrs-site-proposal-process/)

Chapter 4 The ecological values of shellfisheries in Hawai`i

4.1. Introduction

For centuries the mauka makai paradigm has been a central element to Kānaka Maoli management, as exemplified by the ahupua`a system (Handy et al. 1972, Handy and Pukui 1998), and which is described in the previous chapter. Wetland and estuarine systems have largely disappeared across the Main Hawaiian Islands (MHI), and today represent less than one percent of coastal ocean areas, compared to O`ahu estuaries that once occupied 48% of the land (Nelson et al. 2007). Recent changes in the coastal environments suggests they are becoming less efficient filters (Schubel and Kennedy 1984, Office of State Planning 1996). The management of land-based activities can affect the coastal environment. For example, both freshwater inputs and sediment have been shown to impact coral reef ecosystems (Brown and Holley 1982, Friedlander et al. 2008). Sediment discharge is probably the leading cause of alteration of reef community structure in Hawai`i (Friedlander et al. 2008), and pollution runoff is a major cause of water quality degradation across the MHI (Department of Health 2013c). Furthermore, stream channelisation and urban development has intensified freshwater and sediment loading during floods (Gordon and Helfrich 1970, Devaney et al. 1982, Office of State Planning 1992). The consequences of increasing inputs within estuarines, could impact many of the services and values they provide within their systems and to near shore coastal environments.

O`ahu was listed as a one of the top seven most heavily contaminated shellfish sites in the United States(Ahmed 1991). Effective management of estuaries requires identifying anthropogenic impacts on ecological indices, such as water quality. Under the United States Clean Water Act (CWA; in Section 1.2) it is mandatory for states to identify waterbodies not achieving the quality standards through Water Quality Limited Segments (WQLS), nonpoint source pollutants, and water pollution control programs (HCZM 1996, Department of Health 2013a). Approximately 575 marine water body segments, inclusive of estuaries, are established statewide. The water quality pollutants parameters include bacteria, nutrients, turbidity, and chlorophyll *a*. Of the 575 areas, the data of 160 (28%) were assessed, and 136 (85%) of these did not meet the water quality standard for at least one or more pollutant (Department of Health 2014). Certain sites within the current study area, Kāne`ohe Bay, did not meet the water quality standard for at least one or more pollutant. Turbidity and nutrients were the main indicators of poor water quality in the bay (Department of Health 2014). Turbid waters indicate high concentrations of fine suspended sediment, and this may cause a range of environmental damage, including benthic smothering, blockage of fish gills, and transport of sorbed contaminants (Davies-Colley and Smith 2001b). Anecdotal evidence on clam mortalities suggest that these are due to the smothering of the benthic communities (Yap 1977).

On O`ahu, most trace element transport was associated with suspended particulate matter (SPM), including the Kāne`ohe watershed (De Carlo et al. 2004). The SPM concentrations of barium, cobalt, copper, lead, and zinc were associated with urban anthropogenic enrichment (De Carlo et al. 2004). Concentrations of arsenic, cadmium, lead, and zinc in streambed sediment, from O`ahu and Kaua`i, were substantially higher in developed areas than undeveloped areas (Brasher and Wolff 2007). Also, differences in macroinvertebrate species composition, diversity, and abundance were associated with elevated concentrations of contaminants at the developed sites compared to the undeveloped sites (Brasher and Wolff 2007).

Accumulation of contaminants by biological filter feeders and the structure of benthic environments are key indicators utilised within scientific monitoring and assessments. The World Mussel Watch bio-indicator species Pacific oysters, *Crassostrea gigas* (Goldberg et al. 1978) was examined in the bay for the first time in 1995, and showed elevated contamination near stream mouths within the urbanised sector (Hunter et al. 1995). Elsewhere in O`ahu, the water quality of beach sites adjacent to stream mouths, where there was no buffer zone, were most impacted by nutrient loadings from streams (Laws et al. 1999). In addition to this, sediment levels of contaminants have exceeded the sediment quality guidelines for aquatic toxicity in the bay (NOAA 1989a, Hédouin et al. 2009, NOAA 2010).

Since clam beds and loko i`a receive direct stream water input, they are vulnerable to land-based anthropogenic input. The State of Hawai`i waterway monitoring results showed water quality levels exceeded the recreational health standards at specific sites within Kāne`ohe Bay. In the southern sector of the bay, where clam beds were surveyed in the past (Yap 1977, Haws et al. 2014), Kokokahi Pier did not attain safe *Enterococci* levels (Department of Health 2014). Conversely, in the northern sector, the Kualoa ahupua`a, attained safe *Enterococci* levels (Department of Health 2014). Kualoa is adjacent to Hakipu`u (Figure 3.3, Chapter 3) where the shellfish operation in Moli`i loko i`a in Hakipu`u ahupua`a was classified as a shellfish-growing area in Hawai`i (Department of Health 2013b). The Hakipu`u ahupua`a has a more natural landscape, no direct stream input, and is privately owned and managed compared to the southern sector, which has higher landscape development (Table 3.9, Chapter 3). According to the Department of Health records there was 'insufficient data' for water quality monitoring at three streams Kamo`oali`i, Kāne`ohe, Kāwā, located in the southern sector (Department of Health 2014). Haws et al. (2014) reported their unpublished findings of aquaculture trials in the loko i`a of He`eia (Figure 3.3, Chapter 3) and Moli`i, and found the *C. gigas* spat reached larger sizes sooner at the latter site (Haws et al. 2014). Compared to Moli`i, He`eia had direct stream input, a residential and conservation landscape, with both wetland-based and loko i`a wall restoration activities (Chapter 3). Contamination from landscape development travelling via stream input may negatively affect water quality and shellfish health.

In summary, previous shellfish research has illustrated a variation of impacts to introduced shellfish and very little attention towards native species. In the past, the introduced clam, *R. philippinarum*, had massively declined and were more abundant than the native clam(*T. palatum*) in the southern more urbanised sector (Yap 1977). Over time, aquaculture trials of *C. gigas*, *C. virginica*, *R. philippinarum* and in loko i`a, had failed to establish in the lower north, mid, and southern sectors (Brick 1970, Pryor 1974, Haws et al. 2014). However, aquaculture trials found *C. gigas* spat performed well, in Moli`i loko i`a (Haws et al. 2014). Moli`i loko i`a was located in the more natural landscape of the upper north sector and has recently classified as a shellfish-growing areas (Department of Health 2013b). Furthermore, metal contaminant levels in *C. gigas* along the bay were found elevated near stream mouths in the southern sector (Hunter et al. 1995). Exceedingly high levels of metals in sediment were also found in the southern sector, particularly near Kāne`ohe Stream (De Carlo et al. 2004, Hédouin et al. 2009). Within the previous chapter, the landscape development intensity (LDI) index did not evenly increase from north to south. Certain ahupua`a within the north and south sectors, had higher impervious surfaces and channelised streams. Both the LDI and impervious surfaces area would be evaluated within this current study to investigate trace metal sources. This multiple method approach could provide further knowledge into monitoring and management of shellfish environments Kāne`ohe Bay.

This chapter presents an evaluation of current densities and population structure of five clam benthic clams and the Pacific oyster (*C. gigas*), in addition to investigating sediment and *C. gigas* tissue concentration of trace metals (Table 4.1). This evaluation provides new population information, with only *R. philippinarum* and *T. palatum* populations surveyed in the past (Higgins 1969, Yap 1977, Haws et al. 2014). The *C. gigas* trace metal study replicates a previous study in Kāne`ohe Bay of this bioindicator species (Hunter et al. 1995). It allows comparisons of sediment trace metal to the past findings, indicating any persistant nature of metals. These findings can then be tested for correlations with the current environmental variables, and the landscape evaluation data (Figure 4.1). The shellfish ecological values (current chapter) are utilised with the socio-cultural values and landscape indicators (Chapter 3) to evaluate fisheries management decisions more holistically, and guide towards best management practices. The associations between the landscape, shellfish ecology, and contaminant levels have not been investigated previously in Kāne`ohe Bay.

Table 4.1. The study species, the ecological status (native, endemic, or introduced), and the associated scientific classification.

Species	Ecological status, scientific family (in bold), and synonymous names
Tellina (*Quidnipagus*) *palatum* Iredale	Native species. **Tellinidae.** *Tellina rugosa* Born, Lynge, 1909, *Tellina palatum* (Iredale 1929), Study references: *Quidnipagus palatam* (Yap 1977) and *Tellina* (*Quidnipagus*) *palatum* in O`ahu (Haws et al. 2014).
Loxoglypta obliquilineata	Native species. **Tellinidae**
Ctena bella (Conrad 1837)	Native species. **Lucinidae**
Lioconcha hieroglyphica	Native species. **Veneridae**
Ruditapes philippinarum	Introduced species. **Veneridae.** *Tapes philippinarum* (Adams and Reeve 1850), *Venerupis philippinarum* (Adams and Reeve 1850), *Ruditapes philippinarum* (Adams and Reeve 1850). Study references: *Venerupis philippinarum* in O`ahu (Devaney et al. 1982), *Tapes philippinarum* in O`ahu (Higgins 1969, Yap 1977), *Ruditapes philippinarum* and Manila clam in China and O`ahu (Zhao et al. 2012, Haws et al. 2014), and Japanese name Asari (Cahn 1951).
Crassostrea gigas (Thunberg, 1793)	Introduced species. **Ostreidae.** Pacific oyster, Japanese oyster, Miyagi oyster.

4.1.1. Shellfish in Hawai`i

There is a paucity of shellfish ecological research in Hawai`i. Both the aquaculture trials and existing clam bed surveys have been inconsistent over time. Six or seven common species make up about 50 percent of the mollusc assemblages (Kay 1979). Some of the Hawaiian marine molluscs are common across the Pacific making them comparable indicator species for environmental stress, such as pollutants. For instance, the distribution of the edible tellin, *Tellina palatum*, and the beautiful clam, *Ctena bella*, are distributed throughout the Indo-West Pacific (Kay 1979). The oblique-lined tellin, *Loxoglypta obliquilineata*, and the hieroglyph clam, *Lioconcha hieroglyphica*, were described in the Hawaiian Islands, while the shell colour patterns of the latter clam similarly occurred in the Mariana and Marshall Islands (Kay 1979).

The use and names of some of the species above were documented in the past as important bivalves to Kānaka Maoli. `Ōlepe is given to *Tellina* (*Quidnipagus*) *palatum*, and `ōlepe-kupe (literally native clam) to *C. bella* (Pukui and Elbert 1986). It is most likely that the name `ōlepe was differentiated to several names according to the types of bivalves available (Titcomb et al. 1978). The edible tellin was uncommon in the market (Titcomb et al. 1978). The introduced Japanese-littleneck clam, *Ruditapes philippinarum*, was also given a Hawaiian name, pūpū-`ōlepe (Pukui and Elbert 1986). Both the *T.*

palatum, and *R. philippinarum* were found in the last remaining clam fishery site, Kāne`ohe Beach (Yap 1977). The native clam was lower abundance than the introduced clam (Yap 1977).

Several kinds of shellfish were introduced to Kāne`ohe Bay with varying success rates. Between the shellfish were two of the bivalves in this study, *C. gigas*, introduced in 1926, 1938-39 (Harris 1977, Devaney et al. 1982), and *R. philippinarum*, introduced in 1920, 1935, and 1937 (Devaney et al. 1982). *R. philippinarum* was established in the southern sector where it had become commercially and recreationally used for food (Higgins 1969). It's popularity was noted in an illustration of people streaming into the bay during the opening season in September 1968 (Titcomb et al. 1978). Synonymous names of *R. philippinarum* and *T. palatum* are noted, more so for the introduced clam (Table 4.1). The comparison of local *R. philippinarum* across survey literature (Higgins 1969, Yap 1977, Haws et al. 2014) and with the current study is on the basis that this is the same species (Table 4.1).

Shellfish harvesting has been prohibited for a long time in Kāne`ohe Bay, and on O`ahu Island. Harvesting both *R. philippinarum* and the native pearl oyster, *Pinctada galtsoffi*, closed in the 1970's on O`ahu Island (Harris 1977). The seven established *R. philippinarum* beds depleted to one bed at Kāne`ohe Beach Park (Yap 1977). Reported within a news article of the time, the closure of the *R. philipinarum* fishery was due to the demise of the population from soil erosion associated with heavy rain (Titcomb et al. 1978). In their studies, the mass decline of *R. philippinarum* was attributed to over-harvesting, poor management (Higgins 1969), crab predation rates (Higgins 1969, Yap 1977), and poor population recruitment (Yap 1977). Further anecdotal observations of clam mortality had occured with sediment and freshwater input caused by heavy rain and habitat modifications (Yap 1977). Freshwater runoff and flooding were significant factors in the southeast portion of the bay and following rainstorms plumes were often visible over substantial areas (USAEC 1978). Major storm floods in 1965 and 1987 led to significant mortality of benthic organisms on shallow reef flats and slopes in Kāne`ohe Bay (Banner 1968, Jokiel et al. 1993). However, sediment smothering, rather than freshwater flooding, was the anecdotal cause of mortality. This is because silt concentrations are known to inhibit filtration rates in bivalves (Loosanoff 1962), and this species was extremely tolerant of salinity change (Cahn 1951, Higgins 1969). This is potentially common in Hawai`i, as the species diversity of molluscs is higher in subtidal coral communities compared to silted reef flats or in stressed subtidal environments (Kay 1979).

4.1.2. Objectives

The chapter objective was to evaluate the shellfish ecological values of Kāne`ohe Bay. The specific objectives of this chapter were to:

1. Evaluate the current densities and population structure of clam populations and the Pacific oyster, *C. gigas*, populations across the bay. In addition, to evaluate the condition index of *C. gigas* samples and compare this with previous data.
2. Determine tissue trace metal concentration of *C. gigas*, and sediment trace metal concentrations of clam beds, and compare this with previous data locally and globally. Additionally, to evaluate the risks to shellfish populations and the health risks of consuming shellfish.
3. Determine the association between the land development intensity (Chapter 3) of the catchment with shellfish indices and trace metal concentrations.
4. Combine the shellfish ecological and the socio-cultural value findings (Chapter 3) to inform fisheries management decisions.

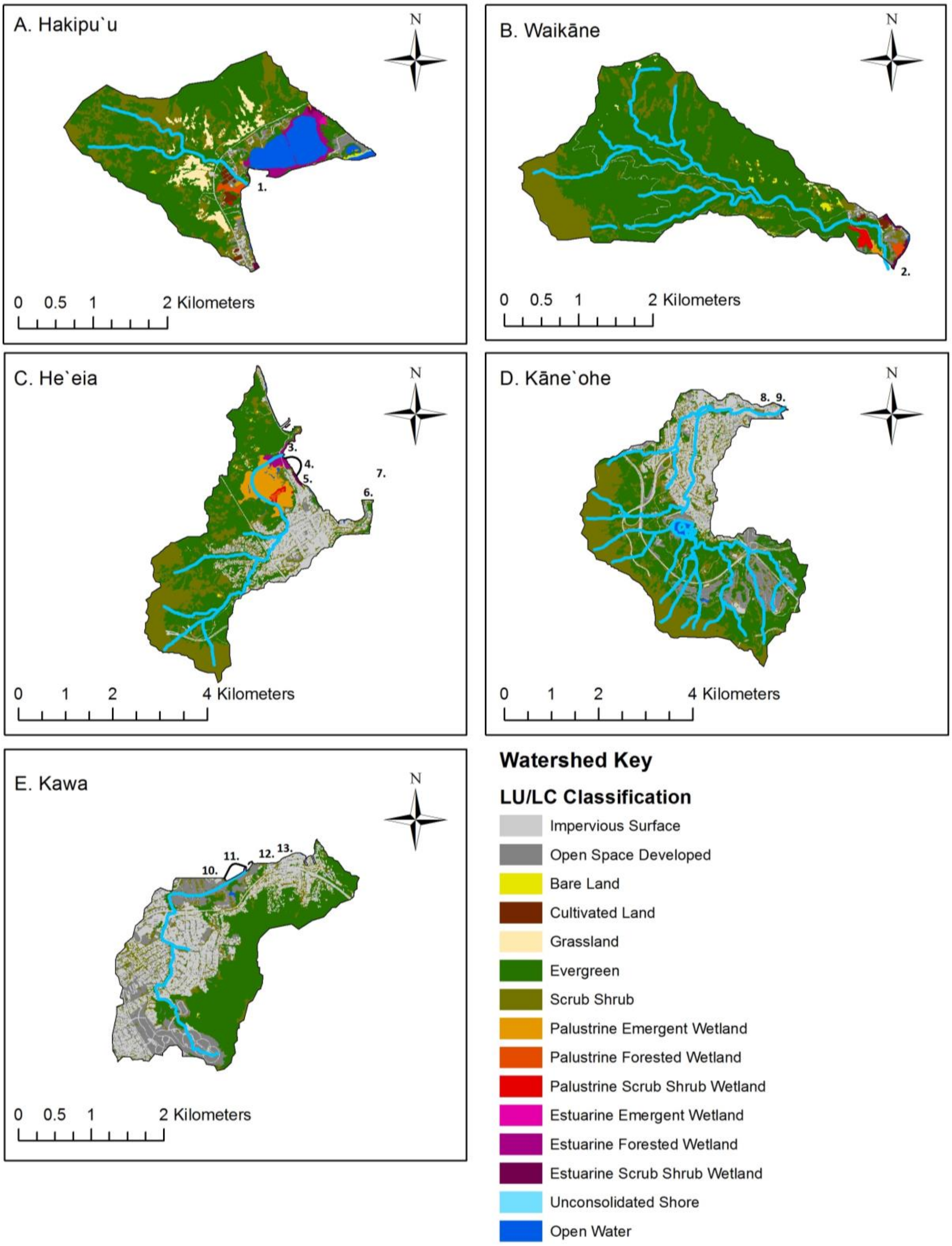


Figure 4.1. The 2005 land use land cover (LU/LC) classification of the study ahupua`a arranged from north to south (A-E) in Kāne`ohe Bay (OP 2005) and the shellfish study sites (numbered 1-13).

4.2. Methods

This section provides the research methodology unique to the shellfish ecology and evaluation in Kāne`ohe Bay. The general laboratory and landscape index methodology was provided in Chapter 2.

4.2.1. Site selection

Shellfish survey sites were selected along the north-to-south sectors in Kāne`ohe Bay, O`ahu (Figure 4.1). There are fourteen ahupua`a with nine perennial streams within the Ko`olaupoko Moku with nine of these in the Kāne`ohe Bay area. Thirteen study sites were selected within five ahupua`a to include past clam beds in the south, and oyster sites along the bay (Figure 4.1). Potential shellfish sites were selected from previous literature (Higgins 1969, Yap 1977, Hunter et al. 1995, Haws et al. 2014), as well as suggestions from local researchers and local practitioner/experts were identified using Google Earth and ArcGIS. The latitudinal and longitudinal coordinates for each site were recorded using a handheld Global Position System (GPS) unit (Appendix 4.1).

Five clam bed sites were selected in the southern section of the bay (Table 4.2, Figure 4.1). Two of the clam beds, KBP and HSP, were previously surveyed (Higgins 1969, Yap 1977, Haws et al. 2014), and another clam bed, YWCA, was previously mapped (Higgins 1969). Two additional sites were selected, Waikalua (W) and He`eia (H), as paired sites to KBP and HSP. The W and KBP sites lay either side of the Kāne`ohe Stream mouth, and W nearest the Waikalua loko i`a. The HSP site was nearest the He`eia stream mouth, adjacent from this site was the He`eia loko i`a, and next to that was the He`eia site.

There were eight *C. gigas* population sites located along the north to south sectors of the bay. A range of sites along the bay was selected as representative of the more rural/agricultural in the north and largely urbanised in the southern sector of the bay (Devaney et al. 1982, Hunter and Evans 1995). These sites consisted of three loko i`a (MLI, HLI, WLI), one island wall (Moku o Lo`e, Coconut Island), and four piers (WP, LP, KP, YP, 0). The loko i`a and most of the piers (except WP) were privately owned. Moku o Lo`e lies adjacent to Lilipuna Pier, both privately owned by the Hawai`i Institute of Marine Biology (HIMB).

The City and County of Honolulu tax map key was used to identify landowners, and permission to access sites was then sought through state, city and county, and private landowners. Three loko i`a organisations and HIMB were contacted and consulted with prior to any research. A preliminary assessment of suggested sites checked for clam presence. A Special Activity Permit was granted by DLNR (Department of Land and Natural Resources, State of Hawai`i) for the collection and release of various live marine clams and oysters for an exploratory study on population status within the bays of

Kāne`ohe, Maunalua, and Waimanalo on O`ahu, as issued for 11/12/2013–31/03/2014. The permit included Hawaiian clam (*T. palatum*), cherrystone clam (*Mercenaria mercenaria*), coral rock oyster (*Crassostrea amasa*), Pacific and Eastern oysters (*C. gigas* and *C. virginica* respectively), and the Japanese littleneck clam (*R. philippinarum*).

Table 4.2. Clams (multiple species) and oyster (*Crassostrea gigas*) sites along the north to south ahupua`a in Kāne`ohe Bay. Selected sites were chosen for oyster tissue or sediment trace metal analysis.

Ahupua`a	Site	Habitat Type	Shellfish	Tissue	Sediment
Hakipu`u	Moli`i Loko I`a (MLI)	Wall	Oyster	Yes	-
Waikāne	Waikāne Pier (WP)	Pier	Oyster	Yes	-
He`eia	He`eia State Park (HSP)	Benthic	Clam	-	Yes
	He`eia Loko I`a (HLI)	Wall	Oyster	Yes	-
	He`eia (H)	Benthic	Clam	-	Yes
Kea`ahala	Lilipuna Pier (LP)	Pier	Oyster	Yes	-
	Moku o Lo`e (M)	Wall	Oyster	Yes	-
Kāne`ohe	Kāne`ohe Pier (KP)	Pier	Oyster	-	-
	Kāne`ohe Beach Park (KBP)	Benthic	Clam	-	Yes
Kāne`ohe and Kāwā	Waikalua (W)	Benthic	Clam	-	Yes
	Waikalua Loko I`a (WLI)	Wall	Oyster	Yes	-
Kāwā	YWCA Pier (YP)	Pier	Oyster	-	-
	YWCA (YWCA)	Benthic	Clam	-	-

4.2.2. Shellfish study design

Clam survey

The clam survey was conducted in January and February 2014 using a systematic sample design (Yap 1977, Haws et al. 2014). Using a 0.1 m² (31.5 cm x 31.5 cm) quadrat and a shovel, *T. palatum*, *R. philippinarum*, and other live clams present, were extracted at low tide to a depth of 10 cm every 10m along three eighty-metre transect lines that ran perpendicular to the shoreline at each site. According to Higgins (1969), who dug to 10 cm, *R. philippinarum* was not found to live much below 7cm. The extracted material was washed with a 2.5 mm sieve so that the clams were free of substrate. The live clams in each sample were identified (Table 4.1), measured for length (mm) using callipers, and then returned to their individual stations. The population sizes were too small for further laboratory analysis. Sediment samples were extracted at sites (Table 4.2) using an 8.5 cm diameter corer to a depth of 10 cm at the 30m and 50m mark along each transect, with additional samples at 10m and 70m along the middle transect. Each sediment sample was placed in a labelled bag, onto ice in a cooler, and taken to the Hawaii Pacific University (HPU) laboratory for analysis.

Clam densities

The mean density of clams, *T. palatum* and *R. philippinarum*, were calculated using the 'positive' quadrat in previous research (Yap 1977, Haws et al. 2014). The 'positive' quadrat does not include the samples that had no clams present. In this current study, the 'total' quadrat samples were used to calculated mean density (individuals per m^2). Therefore, to compare to past studies additional calculations were made of the mean 'positive' density. In addition to this, using past study estimates, the 'total' mean density were recalculated. Furthermore, there are differences in quadrat sizes and sampling design between the clam surveys. Yap (1977) used a 15 cm x 15 cm quadrat along four transect lines with a distance of 1to 10 m, sample sieved with 1.98 mm mesh size (but did not effectively retain clams less than 3 mm) and a total of 210 quadrats at KBP. Yap (1977) had also collected sediment for particle analysis. Haws (2014) who surveyed in 2010, used a 50 cm x 50 cm quadrat every 5 meters and changed to every 10 metres along a 100 m transect, with a total of 10 quadrats at KBP and 15 quadrats at He`eia State Park (HSP). The current study used a $0.1m^2$ quadrat with 3 transect lines of 80m length sampled every 20m, with a total of 27 quadrats per site (135 total all sites) including HSP and KBP, with sediment samples taken at each study site.

C. gigas study design

The *C. gigas* survey was conducted from February to April 2014 using a systematic sample design. Using a 1-m^2 quadrat and callipers, oyster length (mm) was measured on piers and walls along a 100 m transect line. The transect line was extended until at least 100 *C. gigas* indivudals were measured. The survey line ran perpendicular to the shoreline when surveying walls, and ran parallel when surveying piers. A sample of 17-20 *C. gigas*, of a range of sizes that represented the population structure, was collected at each permitted site (Table 4.2.). A total of 76 quadrats were surveyed. Permission to carry out sampling was sought from private owners prior to any fieldwork. The oyster and sediment samples were placed into labelled containers, placed on ice, then returned to the HPU laboratory. Both the trace metal sediment and *C. gigas* tissue samples were oven dried in acid-washed vials and sent to the University of Canterbury for trace metal analysis (Section 2.4, Chapter 2). The methodology for condition index and sediment grain size is also provided within Chapter 2.

Species identification

Five clam species were identified in this study (Table 4.1) by referring to Hawaiian Marine Shellfish (Kay 1979) and Japanese clam literature (Cahn 1951), as well as discussing these with the Collection Technician (Malacology) at the Bernice Pauahi Bishop Museum, O`ahu. The adductor muscle scar and shell colour of oysters were required to identify between species in Hawai`i (Brick 1970, Kay 1979). The adductor muscle scar of *C. gigas* had a lighter colour (faint/light purple, tan or white) than the Eastern oyster, *C. virginica*, where the scar was dark purple/red-brown (Brick 1970, Kay 1979). The native oyster, *Ostrea* sp., had a white muscle scar (Kay 1979). The shell colour of *C. gigas* was dirty white or grey, and *C. virginica* was white/dirty grey (Kay 1979). Commercially grown triploid *C. gigas* shown to me in O`ahu had full stripes (including the ventral region – commonly called the 'lip') of purple or faint colour, with clear muscle scars, and no frills (pers. observation 2014). It was suggested that the colour of the outer oyster shells was due to the surrounding environment. The frilled ventral region is a physical attribute of the native Hawai`i oysters (pers. comm. 2014). Oysters with this attribute were avoided in the survey, and samples opened for laboratory analysis (condition index and trace metals) could be further identified accurately, to record the scar colour. Identification was difficult for samples that were fragile when opening. The oyster samples in this study had purple, light purple, or white muscle scars. The exterior shell of many oysters had striped patterns across the entire shell including the ventral region. Samples with light purple scars were selected when possible for the trace metal analysis.

4.2.3. Regulatory analysis

The wet weight converted *C. gigas* trace metal concentrations (μg g^{-1} soft tissue) were compared to the U.S. FDA Guidelines for public health (U.S.FDA 1993). Sediment trace metal concentrations were compared to the Sediment Quality Guidelines (SQG) developed by NOAA given in Table 4.3 (Long et al. 1995). The SQG defines the concentrations of selected metals and metalloid that have adverse effects on biological organisms. The Effect Range-Low corresponds to the concentrations above which negative effects are more common and the Effect Range-Median corresponds to concentrations at or above which negative effects frequently occur. The recovery values of the Certified Reference Material (CRM) and limit of detection are provided (Appendix 2.5).

Table 4.3. The sediment quality guidelines, with the Effect Range-Low (ERL), and Effect Range-Median (ERM) (Long et al. 1995), for trace metals (μg g^{-1} dry weight), as well as the molluscan food safety guidance level (G.L.; μg g^{-1} wet weight) or no value (n.v.) (U.S.FDA 1993).

	As	**Cd**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**
ERL	8.2	1.2	81	34	20.9	46.7	150
ERM	70	9.6	370	270	51.6	218	410
G.L.	86	4	13	n.v.	80	1.7	n.v.

4.2.4. Statistical analysis

General statistical analysis

All data were checked for normality using Statistica™ Version 13 as described in Section 2.5. When the assumptions of normality were not met and transformation did not improve this, a non-parametric analysis was used (such as dredge oyster density data). The abiotic data, population biology variables, and contaminants were compared spatially and temporally using general linear models, followed by a post-hoc Tukey homogenous test where there was significance (α=0.05).

Distribution and condition index

The *C. gigas* population distribution measures of skewness and kurtosis were calculated using Microsoft Excel™ test. Measuring errors are always a potential problem when calculating condition indices (Crosby and Gale 1990). The gravimetric condition index (CI) samples that were intended for further trace metal analysis were oven-dried in vials, while one site (Moli`i Loko I`a) was not permitted for trace metal analysis, thus foil was used. The CI data consisted of outliers (outside the 95% regression bands at ±2.5 SD) due to measuring errors (2 out of 94) and negative values due to equipment errors (14/94). Once removed, normality assumptions were met, and furthermore, there was no difference in normality between CI foil and vials. Since the homogeneity of the slopes of CI against shell length or width for sites was not significant, a linear regression was used to investigate the relationship between CI and length, and width, for each site. The information from all sites were combined for Kāne`ohe Bay, because there was no significant relationship within sites. Data sets with any evidence of interaction effect of three habitat types (loko i`a wall, island wall, and pier) or combined habitat types (walls and piers) on CI cannot be compared by ANOVA. An ANCOVA (Analysis of Covariance) was used to compare CI, checking that the regression coefficients of the data sets were not significantly different. In the absence of habitat type effect, the data was compared by ANOVA. Post-hoc Tukey homogenous test was run where there was significant difference.

Correlations analysis

The Spearman correlation was used to investigate the relationships between 'land and sea' (e.g. catchment landscape index and site clam density), and the relationships within sites (e.g. environmental condition vs density).. The first correlation analysis included clam densities, landscape indices, sediment metals and MPI_8, and water quality variables (n=24). The second clam data correlation analysis included clam densities, particle grain size, and water quality variables (n=18). The *C. gigas* correlation analysis included *C. gigas* densities, landscape indices, condition index, biological metrics, soft tissue trace metals and MPI_8, and environmental water quality variables (n=20). Statistical significance was set at α=0.05.

A problem with multiple variable correlations is that there could be a high number of false discovery rates (FDR) (McDonald 2009). The Benjamini-Hochberg procedure controlled for this (Chapter 2). A FDR of 5% was applied in this study as used in past studies (Stark and Fowles 2006, Whitney et al. 2010).

4.3. Results

4.3.1. Landscape development and abiotic variables

The catchment Land Development Intensity (LDI) index and impervious surface was generally lower in the northern sector than the southern sector (Table 4.4). Two northern ahupua`a, Waikāne and Hakipu`u, had the lowest LDI (1.25 and 1.67, respectively) and impervious surface (1.37% and 2.38%, respectively). Two southern ahupua`a, Kea`ahala and Kāwā, had the highest LDI (5.42 and 4.30, respectively) and impervious surface (51.08% and 19.78%, respectively).

The mean water temperature range was 20.85-29.12℃, the salinity range was 17.28-31.15 ppt, the mean dissolved oxygen (DO) range was 5.47-8.55 mg/L, and the mean pH range was 7.70-8.27 (Table 4.4). Across clam beds the salinity and pH were statistically significant between at least two sites ($H=22.78$, $DF=4$, $p<0.001$, and $H=10.85$, $DF=4$, $p<0.05$, respectively). Temperature was not significantly different between sites ($H=8.64$, $DF=4$, $p>0.05$). Across clam beds the DO (mg/L) level was significantly higher at Waikalua (W) and lower at Kāne`ohe Beach Park (KBP) ($F=8.31$, $DF=4$, $p<0.001$). Across the oyster sites, temperature, salinity, DO, and pH were significantly different between at least two sites ($H=35.51$, $DF=7$, $p<0.001$; $H=48.21$, $DF=7$, $p<0.001$; $H=30.74$, $DF=7$, $p<0.001$; $H=25.87$, $DF=7$, $p<0.001$).

The sediment composition was similar at HSP and H sites, both were predominantly composed of fine sediment (Figure 4.1). The sediment composition of the three sites further south, KBP, W, and YWCA, was similarly all with high shell/gravel percentage. The sum of ranks for sediment grain sizes across sites highlighted three patterns. The two stream mouth sites, KBP and HSP, ranked higher for coarse and medium sand, KBP also ranked higher for shell/gravel, with all three grain sizes ranked lowest at H (Table 4.5). The most southern site, YWCA, ranked higher for very coarse sand and mud/silt sizes, while H and W ranked lowest for very coarse sand. The paired residential sites, H and HSP, ranked higher for fine sand and very fine sand, with the paired urban sites KBP and W ranked lowest. The sum of ranks patterns of grain size was significant across at least two sites ($p<0.05$, Table 4.5). The mean percent pore water (PW) ranged from 27.06% to 31.74%, which was lower at KBP and higher at He`eia. The mean percent total volatile solid (TVS) ranged from 5.20% to 6.74%, which was lower at He`eia and higher at YWCA.

Table 4.4. Ahupua`a and sites arranged from the north to south, with the associated land values (LDI and impervious surface), low tide *in situ* mean water quality values. Site names are provided in Table 4.2.

Ahupua`a	Site	Shellfish	LDI	Impervious surface %	Temperature (˚C)	Salinity (ppt)	DO (mg/L)	pH
Hakipu`u	MLI	Oyster	1.67	2.38	24.13	27.63	6.08	7.92
Waikāne	WP	Oyster	1.25	1.37	27.76	32.44	8.1	8.27
He'eia	HSP	Clam	2.54	17.22	23.8	17.28	6.89	7.86
	HLI	Oyster	2.54	17.22	25.15	20.9	6.62	8.04
	H	Clam	2.54	17.22	24.35	29.49	6.51	8.31
Kea`ahala	LP	Oyster	5.42	51.08	24.03	27.3	7.23	8.21
	M	Oyster	5.42	51.08	24.73	39.15	5.89	7.7
Kāne'ohe	KP	Oyster	3.08	19.79	24.43	21.73	7.03	8.19
	KBP	Clam	3.08	19.79	20.83	20.39	7.79	7.94
Kāne'ohe & Kāwā	W	Clam	3.69	26.54	23.53	31.65	5.47	8.12
	WLI	Oyster	3.69	26.54	24.27	31.47	7.89	8.22
Kāwā	YP	Oyster	4.3	19.78	29.12	31.43	8.55	8.19
	YWCA	Clam	4.3	19.78	25.35	30.6	7.89	8.19

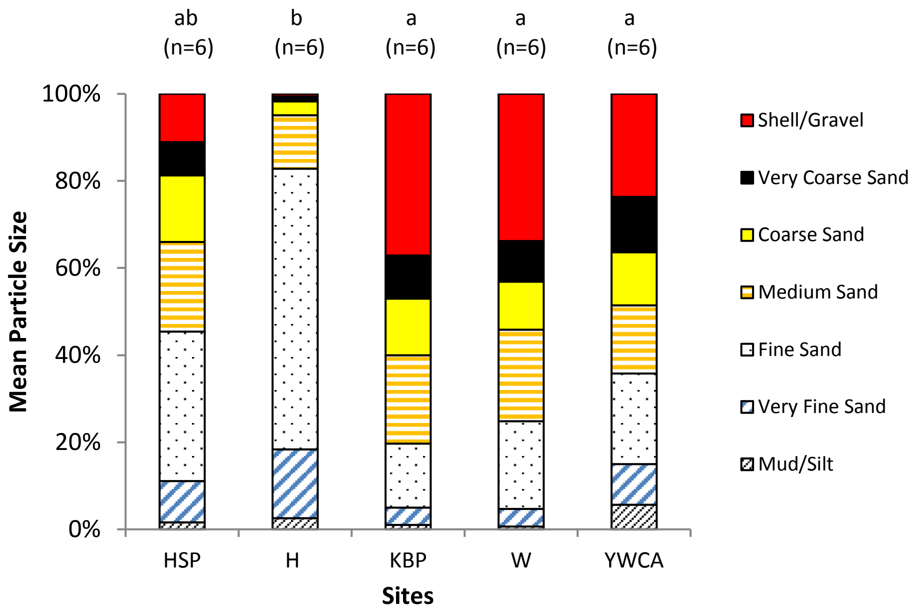


Figure 4.1. Histogram of the mean particle size composition (%) for the clam bed sites (n=6 per site). Site names are provided in Table 4.2.

Table 4.5. Kruskal-Wallis results comparing the grain size composition between the clam bed sites, with significant values in bold. Site names are provided in Table 4.2.

Grain size	Sum of ranks	n	H	p-value
>2mm (Shell/Gravel)	KBP>W>YWCA>HSP>H	6	16.65	**<0.001**
>1mm (Very Coarse Sand)	YWCA>KBP>HSP>W>H	6	13.96	**0.01**
>500µm (Coarse Sand)	HSP>KBP>W>YWCA>H	6	15.84	**<0.001**
>250µm (Medium Sand)	KBP>HSP>W>YWCA>H	6	13.38	**0.01**
>125µm (Fine Sand)	H>HSP>W>YWCA>KBP	6	21.17	**<0.001**
>63µm (Very Fine Sand)	H>HSP>YWCA>KBP>W	6	16.52	**<0.001**
<63µm (Mud/Silt)	YWCA>H>HSP>KBP>W	6	16.12	**<0.001**

4.3.2. Clam and sediment data

Clam densities

Four native clams (*Tellina palatum*, *Ctena bella*, *Lioconcha hieroglyphica*, *Loxoglypta obliquilineata*) and an introduced clam (*Ruditapes philippinarum*) were identified in the current survey. The mean density (total estimates) of each species was highly variable within each site (Figure 4.2). *Tellina palatum* and *Ctena bella* were the most common clams (present at four of the five sites) with a density range of 2.24±1.43-27.31±9.46 per m² and 1.50±0.75-15.34±7.09 per m², respectively. *Ruditapes philippinarum* was present at two sites, KBP and W, with mean densities of 8.23±1.96 and 1.12±1.12 clam per m², respectively. The *L. obliquineata* clam was present at HSP 0.37±0.37, H 7.11±3.27 per m² and YWCA 0.75±0.75 per m². The *L. hieroglyphica* clam was present at W 0.75±0.49 per m² and YWCA 0.75±0.75 per m². Except for *L. hieroglyphica* (H=6.14, DF=4, $p>0.05$), the mean density of *T. palatum*, *C. bella*, *R. philippinarum, L. obliquineata* was significantly different for at least two sites (H=38.11, DF=4, $p<0.001$; H=30.56, DF=4, $p<0.001$; H=78.94, DF=4, $p<0.001$; H=46.38, DF=4, $p<0.001$, respectively; Table 4.6).

The length of all clams was highly variable as shown by the standard error bars (Table 4.7). The mean length (±S.E.) was 14.33±5.12-18.41±0.97 mm for *R. philippinarum*, 19.85±2.48-31.17±3.79 mm for *T. palatum*, 8.82±0.77-16.50±2.78 mm for *C. bella*, 13.00-21.74±1.56 mm for *L. obliquilineata*, and 2.36±5.00-19.50±3.50 mm for *L. hieroglyphica* (Table 4.7).

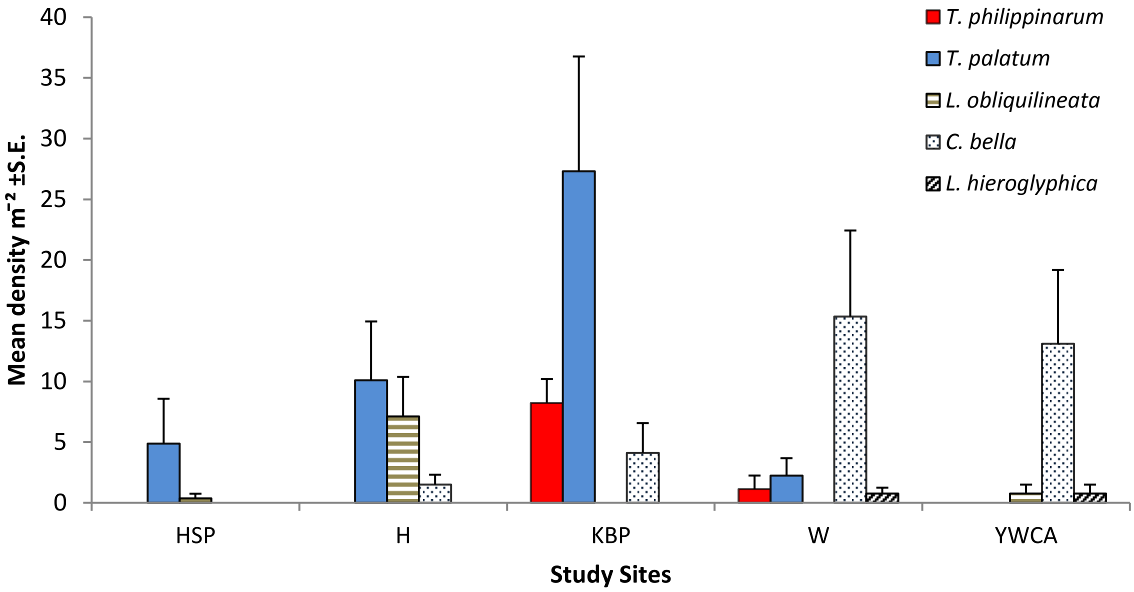


Figure 4.2. Mean density (total individuals per m²) of *Ruditapes philippinarum*, *Tellina palatum*, *Loxoglypta obliquilineata*, *Ctena bella* and *Lioconcha hieroglyphica* across sites. Site names are provided in Table 4.2.

Table 4.6. Kruskal-Wallis results comparing the density of each clam species across sites, with significant values in bold. Site names are provided in Table 4.2.

Species	Sum of Ranks Order	H	DF	P-value
T. palatum	YWCA<HSP<W<H<KBP	38.11	4	**<0.001**
R. philippinarum	HSP=H=YWCA<W<KBP	78.94	4	**<0.001**
L. obliquilineata	KBP=W<HSP<YWCA<H	46.38	4	**<0.001**
C. bella	HSP<H<KBP<W<YWCA	30.56	4	**<0.001**
L. hieroglyphica	HSP=H=KBP<W=YWCA	6.14	4	0.19

Recalculated past clam densities

To compare to past estimates, the current *R. philippinarum* and *T. palatum* densities needed to be re-calculated using the 'positive' quadrats methodology used in past studies (Section 4.2.2.). In addition to this, an estimate clam number per m² was made for past estimates, using the total quadrats (both positive and negative valued quadrats), because this was not done in the past (Table 4.7). These results are given to one decimal place as this was the format available in past literature. Using the positive quadrats, the recalculated 'positive' densities (marked* in Table 4.8.) of *R. philippinarum* at KBP were 861.4 per m² in 1972, 27.2 per m² in 2010, and 11.1 per m² in this current study. The *T. palatum* densities at KBP were 75.5 per m² in 1972, 12.4 per m² in 2010, and 41.0 per m² in this study, and *T. palatum* densities at HSP were 22.0 per m² in 2010 and 26.3 per m² in this study. Using the total quadrats, the *R. philippinarum* population was 695.5 per m² in 1972 at KBP, however, no data per total area was available in 2010 (Table. 4.8).

Table 4.7. Mean length (mm) and size range of each of clam species across sites listed from north to south. Species were not present at all sites, thus had no value (blank). Site names are provided in Table 4.2.

	Mean Length ±S.E. (and size range)				
Site	*T. philippinarum*	*T. palatum*	*C. bella*	*L. obliquilineata*	*L. hieroglyphica*
HSP		19.85±2.48 (11-41)		13.00*	
He`eia		29.48±2.12 (9-46)	16.50±2.78 (9-22)	21.74±1.56 (10-26)	
KBP	18.41±0.97 (6-24)	23.75±1.26 (2-39)	8.82±0.77 (4-13)		
Waikalua	14.33±5.12 (6-19)	31.17±3.79 (21-43)	9.24±0.45 (6-18)		19.50±3.50 (16-23)
YWCA			12.83±0.72 (6-21)	17.50±0.50 (17-18)	2.36±5.00 (8-18)

*Only one *L. obliquilineata* was found at HSP hence there is no size range or S.E.

Table 4.8. The current and recalculated* past densities of *Ruditapes philippinarum* and *Tellina palatum* for positive and total quadrats in 1972 (Yap 1977), 2010 (Haws et al. 2014) at Kāne`ohe Beach Park (KBP) and He`eia State Park (HSP). Past results are reported as given in the literature, the current densities ±S.E. with units provided.

Study Site	**KBP**				**HSP**		
Species	1972	2010	2010*	2014	2010	2010*	2014
R. philippinarum							
Positive quadrats/total quadrats	206/210	10/10	10/10	14/27	0/15	0/15	0/27
Mean no. per positive quadrat	19.4	6.8	6.8	1.1	0	0	0
Mean no. per positive m²	861.4*	3.4	27.2*	11.11±0.02	0	0	0
Mean no. per quadrat (total quadrats)	15.7	not given		0.8			0
Mean clams per m² (total quadrats)	695.5*	not given		8.23±1.96			0
T. palatum							
Positive quadrats/total quadrats	70/210	8/10	8/10	18/27	10/15	10/15	5/27
Mean no. per positive quadrat	1.7	3.1	3.1	4.1	5.5	5.5	2.6
Mean clams per positive m²	75.5*	1.5	12.4*	41.0±0.15	2.7	22.0*	26.3±0.61
Mean no. per quadrat (total quadrats)	not given			2.7	not given		0.5
Mean clams per m² (total quadrats)	not given			27.31±9.46	not given		4.86±3.71

Sediment trace metal concentrations

The mean concentration of trace metals (µg g⁻¹ dry wgt) in sediment from the clam bed sites was variable (Figure 4.3). Sediment As ranged from 10.70-21.77 ppm, Cd was 0.02-0.04 ppm, Co was 5.21-42.20 ppm, and Cr 24.63-150.17 ppm. The sediment Cu concentration was 6.31-30.03 ppm, Mn was 231.19-1614.22 ppm, Ni was 16.30-207.96 ppm, Pb was 3.57-16.78 ppm, and Zn 22.43-105.05 ppm. Lastly, the Metal Pollution Index (MPI_8) score was 7.49-31.21ppm. The concentration of sediment As exceeded the Effect Range-Low (ERL) level at each site, Cr exceeded the ERL at KBP, sediment Ni exceeded the ERL at both HSP and YWCA in addition to exceeding the Effect Range-Median (ERM) value at KBP. The trace metal recoveries of the Certified Reference Material (CRM), limit of detection, and percentage difference between duplicate samples are provided in Appendix 2.5.

Five trace metals (Cr, Mn, Zn, As, Cd) and the MPI_8 were highest at KBP and HSP, while lowest at YWCA and H (Table 4.8). The KBP site ranked highest for the other four metals (Co, Ni, Cu, Pb) and H was lowest for all metals except Pb, which was lowest at HSP. The sum of ranks for each trace metal was statistically significant between at least two sites ($p<0.05$).

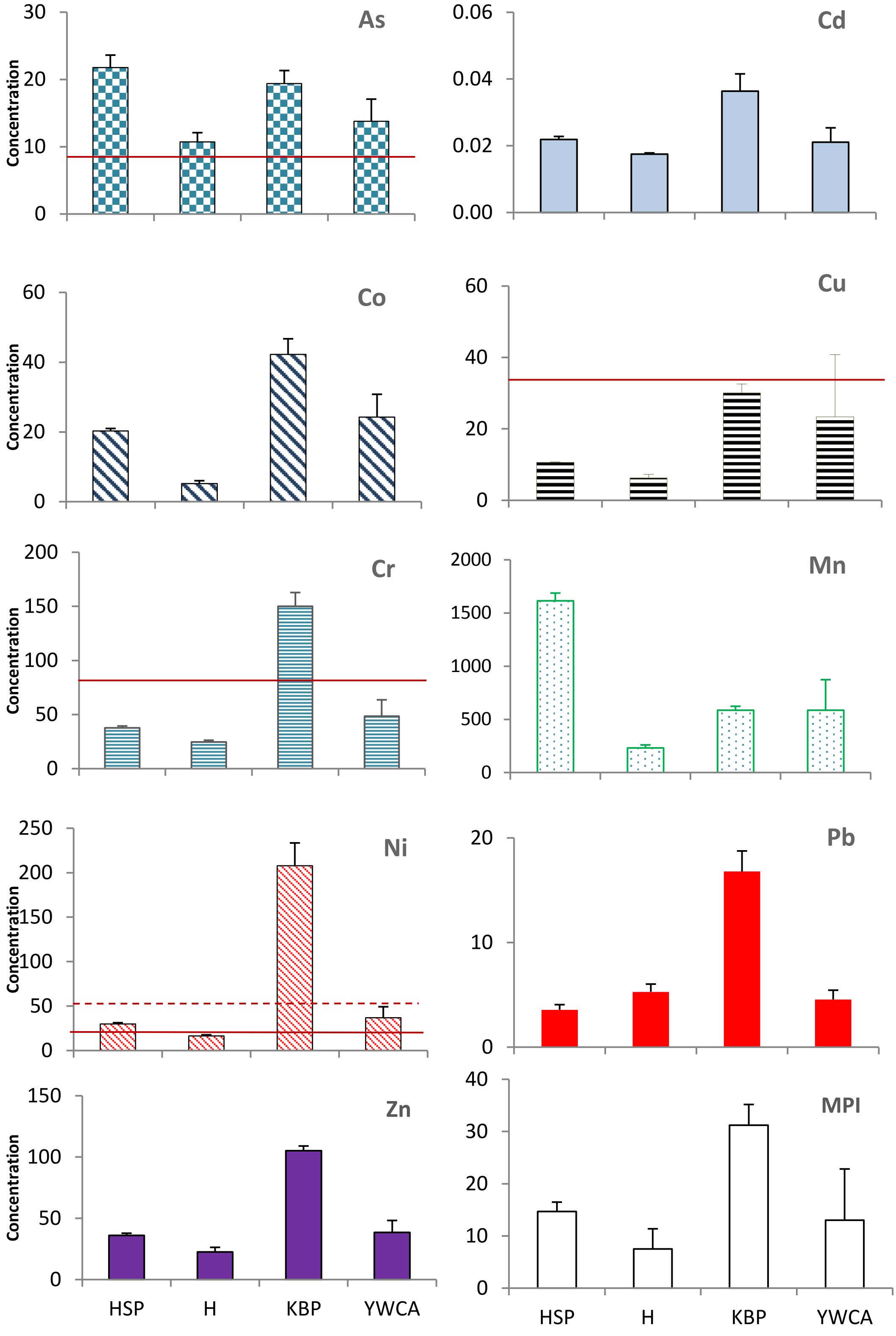


Figure 4.3 Mean concentration of sediment metals and Metal Pollution Index (μg g⁻¹ dry weight ±S.E.) (n=16), with Effect-Range-Low (bold line) and Effect-Range-Median (dashed line) with guideline values provided in Table 4.3. Site names are provided in Table 4.2.

Table 4.8. Kruskal-Wallis results of trace metal sediment concentration (µg g^{-1} dry weight) and MPI_8 between sites, with significant results in bold. Site names are provided in Table 4.2.

Trace Metal	Sum of Ranks	H-value	P-value
As	HSP>KBP>YWCA>H	8.6	**<0.05**
Cd	KBP>HSP>YWCA>H	10.43	**<0.05**
Co	KBP>YWCA>HSP>H	11.85	**<0.01**
Cr	KBP>HSP>YWCA>H	11.37	**<0.01**
Cu	KBP>YWCA>HSP>H	10.08	**<0.05**
Mn	HSP>KBP>YWCA>H	12.25	**<0.01**
Ni	KBP>HSP, YWCA>H	13.33	**<0.01**
Pb	KBP>H>YWCA>HSP	9.97	**<0.02**
Zn	KBP>HSP>YWCA>H	11.24	**<0.01**
MPI_8	KBP>HSP>YWCA>H	13.89	**<0.01**

4.3.3. *Crassostrea gigas* data

C. gigas density

The mean *C. gigas* density (±S.E.) ranged from 3.00±2.10 per m² at Waikāne Pier (WP) in the northern sector to 200.00±40.47 per m² at Kāne`ohe pier (KP) in the southern sector (Figure 4.4). The log-transformed mean density was significantly different between sites ($F(7,46)=14.29$, $p<0.0001$; not shown), and not across habitat types. Across sites, the post-hoc Tukey test homogenous groups illustrated from highest to lowest density was (a) Kāne`ohe Pier, (b) Lilipuna Pier, (ab) Waikalua loko i`a, Moku, YWCA Pier, (bcd) Moli`i loko i`a, (cd) He`eia loko i`a, and (d) Waikāne Pier.

The population distributions of oysters from each site are as follows. The distribution at Moli`i loko i`a (MLI) and Moku o Lo`e (M) were skewed right with right tail extremes ($G_1$range=1.0-2.5). The He`eia loko i`a (HLI) oyster distribution was bi-modal, and Lilipuna pier (LP) was multi-modal. The population sample from all other sites were approximately symmetrical ($G_1$range=0.33-0.85), both KP and Waikalua loko i`a (WLI) were bell-shaped (G_1), and both WP and YWCA pier (YP) were uniformly flat (extreme kurtosis = -0.35 and 0.47 respectively).

The comparison across size classes are as follows (Figure 4.4.). Smallest sized *C. gigas* (1-5mm) were present at HLI, LP, and KP, and above that size class (6-10mm) were present within the populations at MLI, M, HLI, LP, KP, and YP. The largest size (71-81+mm) were only present at MLI, LP, KP, and YP. The log-transformed mean length was significantly larger at piers compared to island and loko i`a walls ($F(2,57)=6.87$, $p<0.01$) The log-transformed mean length was significantly larger at WP and smallest at M, HLI, and MLI ($F(7, 52)=4.15$, $p<0.01$).

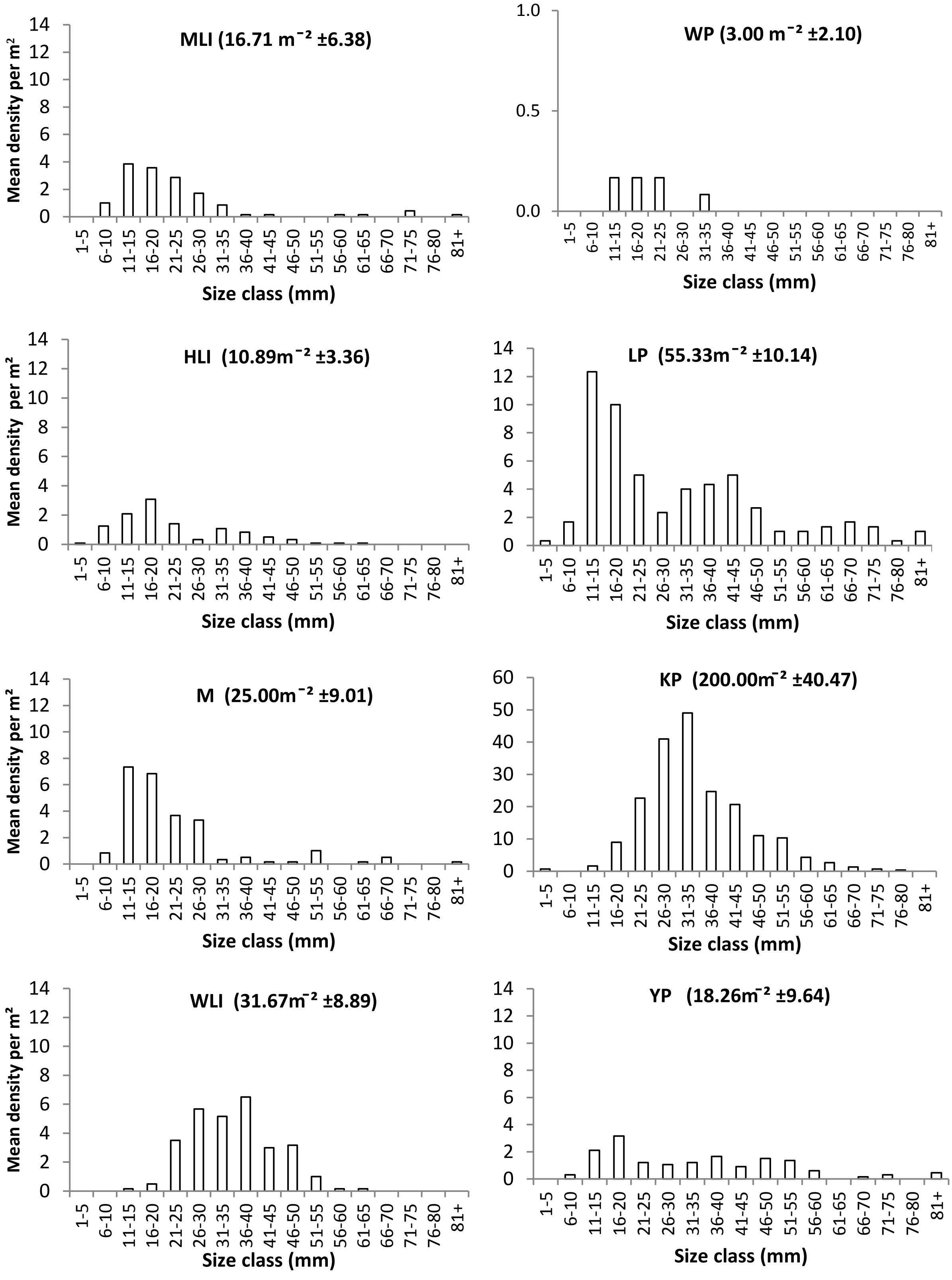


Figure 4.4 Mean *C. gigas* size class density per m² (and mean density per site ±S.E.) arranged from the north to south. Note that Waikāne Pier (WP) and Kāne`ohe Pier (KP) have different y-axis than the other sites due to different population sizes. Site names are provided in Table 4.2.

C. gigas condition index

The mean *C. gigas* length (mm) of the gravimetric condition index (CI) samples were similar across four sites, WP, HLI, LP, WLI, with 48.71±5.48 to 54.83±1.99 mm, and smaller at M and MLI, with 26.67±2.32 mm and 37.75±4.87 mm, respectively (Figure 4.5a). The mean width was slightly more variable; the same four sites (WP, HLI, LP, WLI) had a similarly larger range 30.93±3.34-45.25±8.07 mm than M and MLI, with 20.17±1.35 mm and 26.31±2.71 mm, respectively (Figure 4.5b). Neither the length nor width significantly influenced the mean CI at individual sites (not shown), or the combined sites of Kāne`ohe Bay (Figure 4.6).

Across sites, the CI was highly variable and statistically significantly higher at (ab) MLI, WLI, M, and lower at (b) HLI ($p<0.001$; Table 4.9, Figure 4.7a). Across habitat types, the CI was significantly higher at the island wall (M) and lowest at piers ($F(2,74)=3.26$, $p<0.05$; Figure 4.7b). However, when island and loko i`a walls were combined the CI was not significantly different.

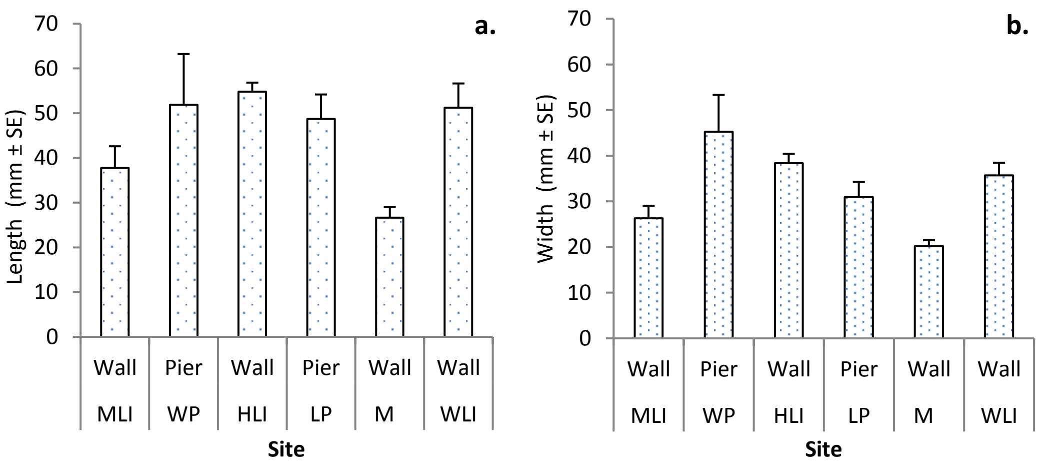


Figure 4.5 (a) Mean length and (b) mean width (mm ±SE) of the *C. gigas* condition index samples. Site names are provided in Table 4.2.

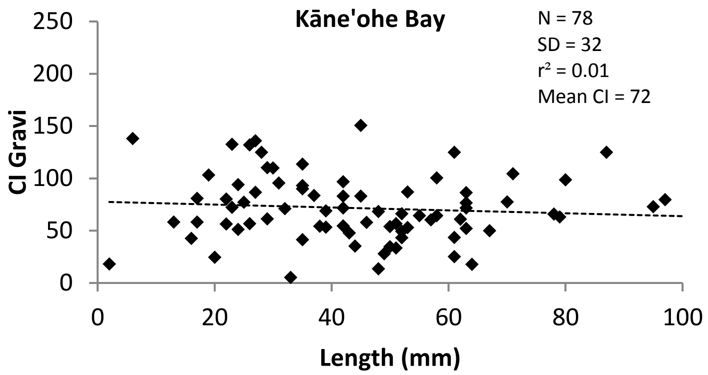


Figure 4.6 Gravimetric condition index (CI Gravi), sample size (N), standard deviation (SD), regression value (r), the mean condition index (CI), and regression line (dashed) of the combined *C. gigas* samples.

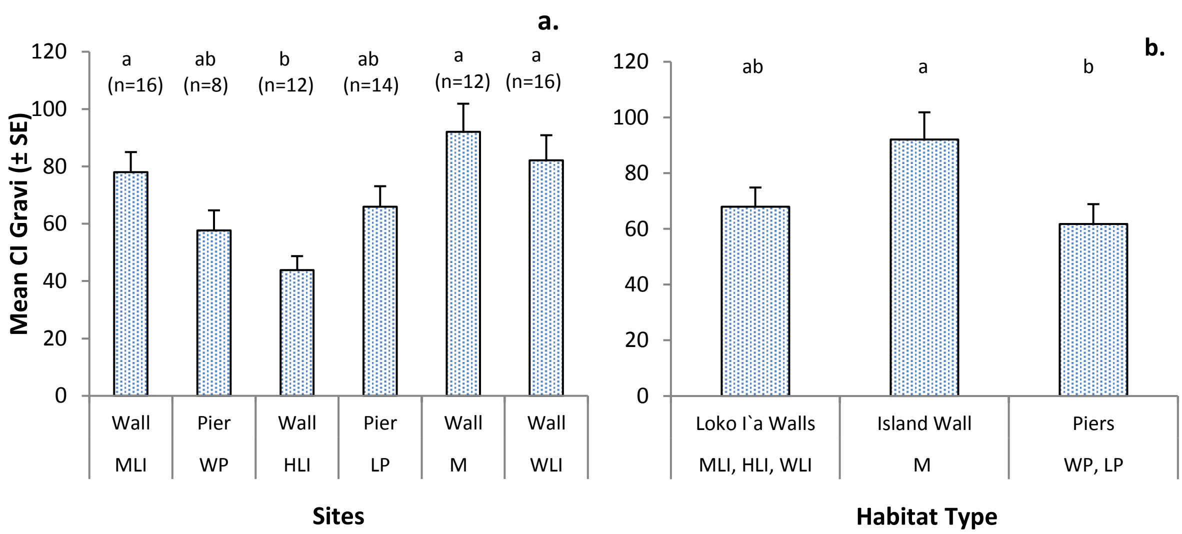


Figure 4.7 Mean gravimetric condition index (±SE) of *C. gigas* across: (a) sites and (b) habitat types. Post-hoc Tukey homogenous groups were given the same letter. Site names are provided in Table 4.2.

Table 4.9. ANOVA results of mean gravimetric condition index of *C. gigas* between sites.

Effect	DF	SS	MS	F	p-value
Sites	5	18724.7	3744.9	4.64	**<0.001**
Error	72	58102	807		
Total	77	76826.66			

C. gigas tissue metal concentrations

The *C. gigas* tissue concentrations (µg g^{-1} soft tissue dry wgt) range are as follows, As was 5.9-29.5 ppm, Cd was 0.2-0.8 ppm, Co was 0.5-0.8 ppm, Cr was 1.1-2.4 ppm, and Cu was 158.8-831.5 ppm (Figure 4.8). The tissue concentration range of Mn was 17.5-44.6 ppm, Ni was 1.1-2.1 ppm, Pb was 0.1-0.4, Zn was 221.8-1588.1 ppm, and the Metal Pollution Index (MPI_8) was 2.6-5.0 ppm. The trace metal recoveries of the Certified Reference Material (CRM) and limit of detection are provided in Appendix 2.5.

Across sites, the *C. gigas* tissue Pb concentration was significantly different between at least two sites (H=10.60, DF=4, $p<0.05$; Table 4.10), as illustrated lower at WP and higher at LP, M, WLI (Figure 4.8). Across habitat types, *C. gigas* tissue Mn concentration was significantly different between at least two habitat types, and illustrated the island (M) was much lower than loko i`a (HLI and WLI) (H=7.15, DF=2, $p<0.01$). The *C. gigas* tissue $MPI_8$ generally increased from the north-to-south sites, however this index and many of the trace metal concentrations were not significantly different across site or across habitat type (loko i`a wall, island wall, or pier).

Table 4.10. Comparing *Crassostrea gigas* tissue trace metal and MPI_8 concentration (µg g^{-1} soft tissue dry weight) between sites and habitat types with significant results in bold. The site results are illustrated in Figure 4.8, and site names provided in Table 4.2

Trace Metal	Sites	H	p-value	Habitat Type	H	p-value
As	LP>HLI>WLI>M>WP	6.55	0.16	Loko>Pier>Island	1.33	0.51
Cd	LP>HLI>M>WLI>WP	6.11	0.19	Pier>Loko>Island	1.10	0.58
Co	WLI>LP>M>HLI>WP	4.56	0.34	Loko>Pier>Island	0.71	0.70
Cr	LP>WLI>M>HLI>WP	6.81	0.15	Pier>Loko >Island	0.37	0.83
Cu	LP>HLI>WLI>M>WP	5.78	0.22	Loko >Pier>Island	2.68	0.26
Mn	WLI=HLI>LP>WP>M	7.56	0.11	**Loko>Pier>Island**	**7.15**	**<0.01**
Ni	LP>WLI>M>HLI>WP	5.87	0.21	Loko>Pier>Island	1.20	0.55
Pb	**LP>WLI>M>HLI>WP**	**10.59**	**<0.05**	Pier>Loko >Island	2.31	0.32
Zn	LP>WLI>HLI>M>WP	8.53	0.07	Loko>Pier>Island	3.29	0.19
MPI_8	WLI>LP>HLI>M>WP	3.49	0.48	Loko>Pier>Island	1.80	0.41

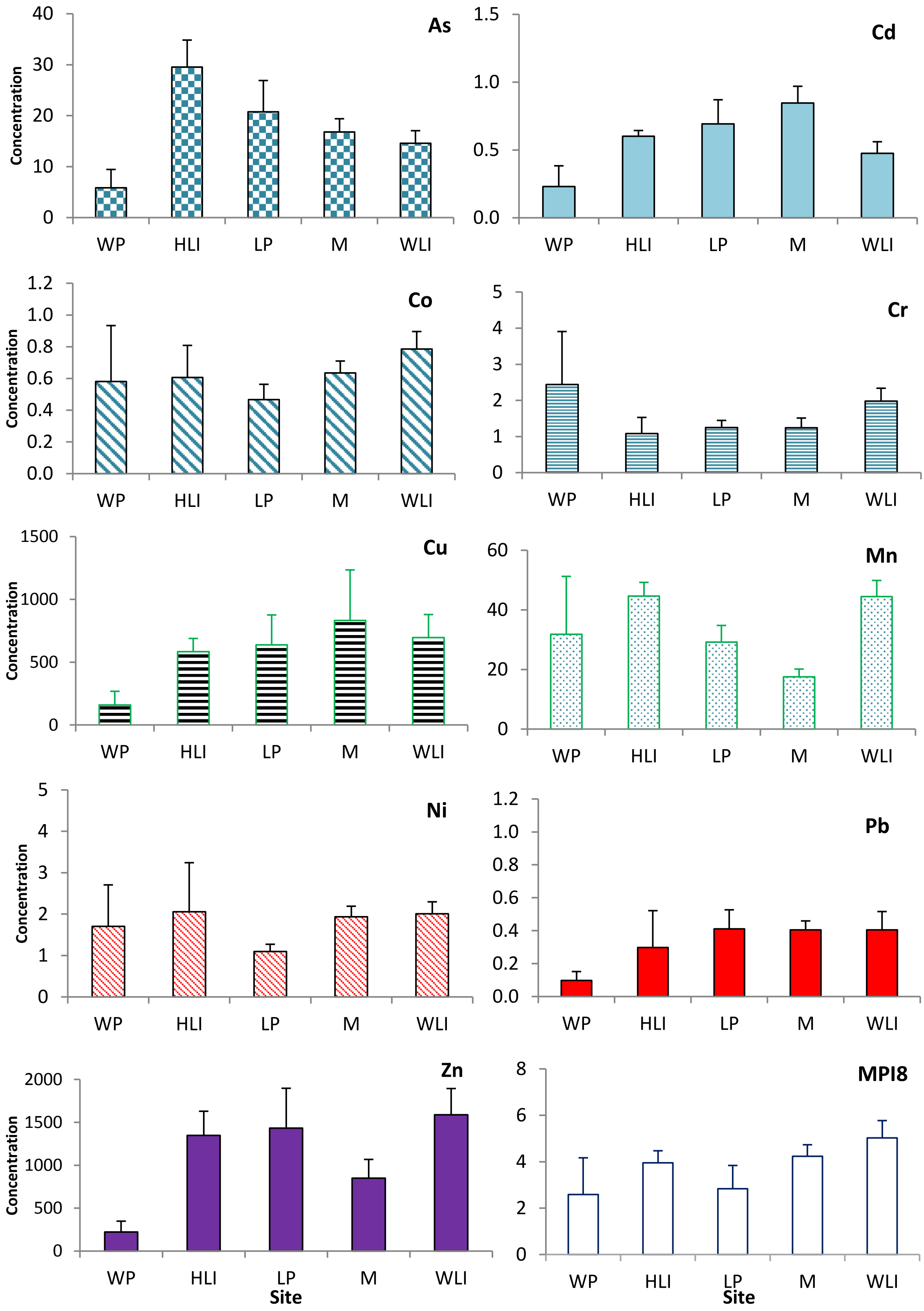


Figure 4.8 Mean element concentrations in *C. gigas* (μg g⁻¹ soft tissue dry weight ±S.E.) and Metal Pollution Index (MPI8). Site names are provided in Table 4.2.

4.3.4. Correlation analysis

Clam data

The correlation tables of the clam data are in Appendices 4.2 and 4.3, and the Benjamini-Hochberg corrected tables are presented here (Table 4.11 and Table 4.12). While the landscape indices were positively correlated to each other (R=0.89, p<0.001), the LDI had fewer significant correlations to clam data than the impervious surface (Table 4.12). The LDI was positively correlated with *C. bella* density (R=0.68, p<0.001), and with salinity (R=0.71, p<0.001). The impervious surface was positively correlated with seven of the sediment trace metals (Cd, Cr, Co, Cu, Ni, Pb, Zn) and the MPI_8 positively correlated to the impervious surface (R=0.61 to 0.77, p<0.05).

The *C. bella* density was also positively correlated with salinity (R=0.80, p<0.0001), and *R. philippinarum* density was negatively correlated with temperature (R=-0.72, p<0.001), and positively correlated with DO (R=0.55, p<0.02). *R. philippinarum* also negatively correlated with fine sand (>125µm) (R=-0.65, p<0.004). The sediment MPI_8 and six trace metals (Cd, Cr, Co, Cu, Ni, Zn) negatively correlated with *L. obliquenata* density (R=-0.62 to -0.74, p<0.05), while six metals (Cd, Cr, Co, Ni, Pb, Zn) and the sediment MPI_8 positively correlated with *R. philippinarum* (R= 0.67 to 0.75, p<0.005).

Table 4.11. The correlation between landscape indices (LDI and Impervious surfaces), clam density, and abiotic data, corrected using the Benjamini-Hochberg critical value (i/m*Q) (m=23, Q=0.05) Significant values are in bold, potential significance italicised, and the spearman coefficient (R) and p-value are given.

	LDI			Impervious Surface		
Variables	R	p-value	Variables	R	p-value	(i/m*Q)
Impervious surface	**0.89**	**<0.001**	LDI	**0.89**	**<0.001**	0.002
C. bella	**0.68**	**<0.001**	Ni	**0.77**	**<0.001**	0.004
Salinity	**0.71**	**<0.001**	Co	**0.73**	**<0.002**	0.007
Cu	*0.55*	*0.03*	Zn	**0.71**	**<0.005**	0.009
Co	*0.50*	*0.05*	Cr	**0.69**	**<0.005**	0.011
Ni	0.46	0.07	MPI_8	**0.69**	**<0.005**	0.013
L. hieroglyphica	0.33	0.15	Cu	**0.68**	**<0.01**	0.015
Zn	0.36	0.17	Cd	**0.66**	**<0.01**	0.017
pH	0.34	0.17	Pb	**0.61**	**0.01**	0.020
T. palatum	-0.32	0.17	*C. bella*	*0.45*	*0.04*	0.022
Cd	0.36	0.17	Temperature	*-0.47*	*0.05*	0.024
L. obliquenata	-0.32	0.18	*L. obliquenata*	-0.41	0.08	0.026
Cr	0.33	0.21	Salinity	0.41	0.09	0.028
MPI_8	0.33	0.21	PW	-0.39	0.11	0.030
PW	-0.24	0.33	*R. philippinarum*	0.36	0.12	0.033
DO	0.23	0.36	*L. hieroglyphica*	0.33	0.15	0.035
Pb	0.20	0.45	DO	0.26	0.29	0.037
Mn	-0.18	0.51	As	0.15	0.57	0.039
TVS	0.13	0.61	TVS	0.13	0.61	0.041
As	-0.05	0.85	pH	0.10	0.69	0.043
Temperature	0.02	0.95	*T. palatum*	0.04	0.88	0.046
R. philippinarum	0.00	1.00	Mn	-0.03	0.93	0.048

Table 4.12. The correlation between clam species' density, sediment trace metals and MPI$_8$, pore water (PW), total volatile solids (TVS), and environmental water quality variables, corrected using the Benjamini-Hochberg critical value (i/m*Q) (m=23, Q=0.05). Significant values are in bold, potential significance italicised, and the spearman coefficient (R) and p-value are given. Abbreviations: Imp. surface (impervious surface), PW (pore water), TVS (total volatile solids), DO (dissolved oxygen), and trace metals.

	L. obliquenata			*R. philippinarum*		
Variables	R	p-value	Variables	R	p-value	(i/m*Q)
Cd	**-0.74**	**<0.002**	Temperature	**-0.72**	**<0.001**	0.002
Ni	**-0.72**	**<0.002**	Cr	**0.75**	**<0.001**	0.004
Co	**-0.71**	**<0.005**	Ni	**0.75**	**<0.001**	0.007
MPI$_8$	**-0.71**	**<0.005**	Zn	**0.74**	**<0.005**	0.009
Cu	**-0.70**	**<0.005**	MPI$_8$	**0.74**	**<0.005**	0.011
Cr	**-0.66**	**<0.010**	Pb	**0.73**	**<0.005**	0.013
Zn	**-0.62**	**<0.012**	*T. palatum*	**0.66**	**<0.005**	0.015
Mn	*-0.53*	*0.03*	Co	**0.67**	**<0.005**	0.017
TVS	-0.45	0.06	Cd	**0.67**	**<0.005**	0.020
Imp. surface	-0.41	0.08	DO	**0.55**	**<0.02**	0.022
pH	0.39	0.11	Cu	*0.55*	*0.03*	0.024
Temperature	0.35	0.16	PW	*-0.49*	*0.04*	0.026
LDI	-0.32	0.18	Imp. surface	0.36	0.12	0.028
PW	0.33	0.19	Salinity	-0.35	0.15	0.030
DO	-0.32	0.19	As	0.32	0.23	0.033
R. philippinarum	-0.25	0.29	*L. obliquenata*	-0.25	0.29	0.035
As	-0.27	0.32	*C. bella*	-0.24	0.30	0.037
Salinity	0.24	0.34	pH	-0.22	0.39	0.039
Pb	-0.21	0.45	*L. hieroglyphica*	-0.11	0.63	0.041
L. hieroglyphica	-0.11	0.63	Mn	0.12	0.66	0.043
C. bella	-0.06	0.81	TVS	-0.11	0.67	0.046
T. palatum	0.05	0.82	LDI	0.00	1.00	0.048
	T. palatum			*C. bella*		
Variables	R	p-value	Variables	R	p-value	(i/m*Q)
R. philippinarum	**0.66**	**<0.002**	Salinity	**0.80**	**<0.0001**	0.002
Temperature	*-0.62*	*0.01*	LDI	**0.68**	**<0.0001**	0.004
Pb	0.47	0.07	Imp. surface	*0.45*	*0.04*	0.007
C. bella	-0.38	0.10	pH	0.45	0.06	0.009
LDI	-0.32	0.17	*L. hieroglyphica*	0.41	0.07	0.011
Salinity	-0.33	0.18	*T. palatum*	-0.38	0.10	0.013
Cd	0.29	0.27	Temperature	0.38	0.12	0.015
Cr	0.26	0.32	Mn	-0.29	0.27	0.017
Mn	-0.23	0.39	PW	-0.26	0.29	0.020
pH	-0.20	0.43	*R. philippinarum*	-0.24	0.30	0.022
Zn	0.20	0.47	As	-0.21	0.44	0.024
Ni	0.19	0.49	Cu	0.16	0.54	0.026
MPI$_8$	0.18	0.50	DO	0.11	0.66	0.028
TVS	-0.12	0.64	Cr	-0.09	0.74	0.030
PW	-0.09	0.73	Co	0.09	0.75	0.033
Co	0.09	0.75	Pb	-0.07	0.78	0.035
L. obliquenata	0.05	0.82	Zn	-0.07	0.79	0.037
Imp. surface	0.04	0.88	*L. obliquenata*	-0.06	0.81	0.039
L. hieroglyphica	-0.02	0.93	MPI$_8$	-0.06	0.84	0.041
DO	-0.02	0.93	Ni	0.03	0.90	0.043
As	0.02	0.96	TVS %	-0.03	0.90	0.046
Cu	-0.01	0.98	Cd	0.02	0.93	0.048

C. gigas data

The correlation tables of the clam data are in Appendices 4.4, and Benjamini-Hochberg corrected tables presented here (Table 4.13 and Table 4.14). The impervious surface and LDI were positively correlated with *C. gigas* density (R=0.81 and R=0.80 respectively, p<0.001) and with *C. gigas* tissue concentrations of Pb (R=0.61, p<0.005), and Cd concentration (R=0.42, p<0.05).

Shell length positively correlated with DO and pH (R=0.30, p<0.002, R=0.27, p<0.008, respectively). Mean density was correlated positively with salinity and negatively with temperature (R=0.43, p<0.001; R=-0.78, p<0.001, respectively).

The *C. gigas* condition index (CI) negatively correlated with tissue As concentration (R= -0.64, p<0.003), while the length positively correlated with tissue Zn concentration (R=0.52, p<0.01). Shell length was also correlated with soft tissue dry weight (R=0.89, p<0.001), density (R=0.30, p<0.002).

Table 4.13. The correlation between the landscape indices (Impervious surface and the Landscape Development Intensity index: LDI) with the water quality metrics, and the *C. gigas* indices (density, trace metal, condition, and size). Significant values are in bold, as corrected using the Benjamini-Hochberg critical value (i/m*Q) (m=20, Q=0.05). The spearman coefficient (R) and p-value are given. Abbreviations: Imp. surface (impervious surface), DO (dissolved oxygen), and trace metals.

	Impervious Surface			LDI		
Variables	R	p-value	Variables	R	p-value	(i/m*Q)
LDI	**1.00**	**<0.001**	Imp. surface	**1.00**	**<0.001**	0.003
Density	**0.81**	**<0.001**	Density	**0.80**	**<0.001**	0.005
Temperature	**-0.43**	**<0.001**	Temperature	**-0.42**	**<0.001**	0.008
Pb	**0.61**	**<0.002**	Pb	**0.61**	**<0.002**	0.011
Cd	**0.42**	**<0.05**	Cd	**0.42**	**<0.05**	0.013
Condition Index	0.19	0.08	Condition Index	0.19	0.08	0.016
DO	-0.15	0.12	DO	-0.15	0.13	0.018
MPI_8	0.27	0.20	MPI_8	0.27	0.20	0.021
Cu	0.23	0.27	Cu	0.23	0.27	0.024
Ni	0.23	0.28	Ni	0.23	0.28	0.026
Cr	0.23	0.29	Cr	0.23	0.29	0.029
pH	-0.10	0.32	pH	-0.10	0.32	0.032
Salinity	0.10	0.32	Tissue dry weight	-0.11	0.33	0.034
Tissue dry weight	-0.11	0.33	Salinity	0.10	0.33	0.037
Zn	0.21	0.33	Zn	0.21	0.33	0.039
Length	-0.09	0.37	Length	-0.09	0.37	0.042
Co	0.16	0.46	Co	0.16	0.46	0.045
As	0.14	0.53	As	0.14	0.53	0.047
Mn	0.06	0.80	Mn	0.06	0.80	0.050

Table 4.14. The correlation between *C. gigas* condition index (CI), length, and density with the following variables: *C. gigas* tissue metal concentration, and water quality variables. Significant values are in bold, corrected using the Benjamini-Hochberg critical value (i/m*Q) (m=20, Q=0.05), potential significance italicised, and the spearman coefficient (R), p-value are given.

	CI			Length			Density		
Variables	R	p-value	Variables	R	p-value	Variables	R	p-value	(i/m*Q)
As	**-0.64**	**<0.003**	Soft tissue dry weight	**0.89**	**<0.001**	Impervious surface	**0.81**	**<0.001**	0.003
Salinity	*0.29*	*0.01*	Dissolved Oxygen	**0.30**	**<0.002**	LDI	**0.80**	**<0.001**	0.005
Density	*0.23*	*0.04*	pH	**0.27**	**<0.008**	Temperature	**-0.78**	**<0.001**	0.008
Cu	-0.44	0.05	Zn	**0.52**	**<0.01**	Pb	*0.46*	*0.02*	0.011
Temperature	-0.20	0.06	Salinity	-0.19	0.06	Condition Index	*0.23*	*0.04*	0.013
Impervious Surface	0.19	0.08	Cu	0.34	0.10	pH	0.18	0.08	0.016
LDI	0.19	0.08	As	0.33	0.11	Zn	0.30	0.15	0.018
pH	-0.18	0.09	Condition Index	-0.12	0.27	Cr	0.27	0.19	0.021
Zn	-0.37	0.11	Imp. surface	-0.09	0.37	Cd	0.27	0.20	0.024
Dissolved Oxygen	-0.16	0.14	LDI	-0.09	0.37	Dissolved Oxygen	0.12	0.23	0.026
Cd	-0.27	0.25	Pb	-0.13	0.54	MPI_8	0.21	0.31	0.029
Length	-0.12	0.27	MPI_8	0.11	0.61	Cu	0.17	0.41	0.032
Ni	0.25	0.29	Temperature	0.05	0.61	Co	0.17	0.42	0.034
Pb	0.21	0.37	Mn	0.10	0.63	Mn	0.12	0.58	0.037
Mn	-0.17	0.46	Ni	-0.09	0.67	As	0.12	0.58	0.039
Soft tissue dry weight	0.07	0.53	Cd	0.08	0.72	Ni	0.11	0.59	0.042
MPI_8	-0.13	0.57	Co	0.06	0.78	Soft tissue dry weight	0.02	0.83	0.045
Cr	0.12	0.60	Density	0.01	0.94	Salinity	0.02	0.85	0.047
Co	-0.01	0.96	Cr	0.01	0.96	Length	0.01	0.94	0.050

4.4. Discussion

The surrounding land use of Kāne`ohe Bay has become a gradient of agricultural and conservation in the north, and increasing urban development in the south (Oki and Brasher 2003, Klasner and Mikami 2005). As receiving bodies of multiple inputs, estuarine systems and their aquatic residents are most at risk of contaminant impacts. Aquatic invertebrates take up and accumulate trace metals all of which have the potential to impair function, or cause toxic effects. This chapter evaluated the shellfish ecological indices in the lower-intertidal zone of Kāne`ohe Bay, and compared these with landscape development indices from Chapter 3. These findings alongside are discussed, and further considered alongside the socio-cultural index findings (Chapter 3) towards management.

4.4.1. Clam population indices and habitat trace metal concentrations

Clam densities

Five clams (*Tellina palatum, Ruditapes philippinarum, Ctena bella, Lioconcha hieroglyphica, Loxoglypta obliquilineata*) were identified in the present survey in the south-east portion of the bay. The clam species' distribution and length range were both highly variable (Figure 4.2, Table 4.6-4.7). Past length data was available for *T. palatum* and *R. philippinarum*, and reproductive size data was available for the latter clam species. The current length of *T. palatum* (19.9-31.2 mm) was a much smaller than previously found at He`eia State Park (HSP) and Kāne`ohe Beach Park (KBP) (<9-35 mm) (Haws et al. 2014). This suggests the smaller clams have grown since 2010 without any recruitment of smaller clams in the sampled populations. Studies of the complete life history of *Tellina* spp. is lacking (Dey 2006), so the size at maturity is unknown. Based on local reproductive tissue and length data for *R. philippinarum* in the bay, the clam reached early stages of maturity at ≥18 mm length and full maturity at ≥20 mm (Higgins 1969, Yap 1977). The sizes in the current study suggested *R. philippinarum* were within the early stages of maturity at KBP (6-24 mm) and Waikalua (6-19 mm,). This stage of maturity was also reported from KBP in 2010 (8-18 mm) (Haws et al. 2014). Larger and more mature *R. philippinarum* were documented at KBP in 1972 (15-35mm) (Yap 1977), and reported near the Marine Core Base Hawai`i (>5-40 mm) during the initial establishment of this fishery (Higgins 1969). The current environmental conditions may not be suitable in Kāne`ohe Bay compared to the clams place of origin, Japan, where it can reach a maximum size of ~70 mm length and 50mm height (Cahn 1951).

The density of two clams, *R. philippinarum* and *T. palatum*, had been previously documented in the southern portion of the bay. The comparison of density data over time (Table 4.8) further supported that the environmental conditions are much less suitable to *R. philippinarum* than *T. palatum*. Past methodology reported clam density for the 'positive' quadrat for both surveys, and only the total quadrat for *R. philippinarum* in the 1972 survey (explained in methods Section 4.23). Since the ‘positive’ quadrats do not consider ‘negative’ quadrats, i.e. no clams present, the past estimates would most likely be overestimates. This is evident for the *R. philippinarum* density at KBP in the current study was 8.23±1.96 clams per m² (total quadrats) compared with 11.11±0.02 clams per m² (positive quadrats, Table 4.8). Compared to the 1972 density at KBP, only 1.18% of the *R. philippinarum* density (total quadrat) and 54.30% of the *T. palatum* density (positive quadrat) remains (Table 4.8) (Yap 1977). In contrast to 1970, the current clam ratio of *T. palatum* density is higher than *R. philippinarum* at KBP (Yap 1977). In addition to this, *T. palatum* density (positive quadrat) has increased at both KBP and HSP sites since the 2010 study, while *R. philippinarum* density (positive quadrat) continued to decline (Table 4.8) (Haws et al. 2014). According to Kay (1979), *T. palatum* reportedly burrowed to depths of 2-3 m, which is much deeper than was studied in the past and present study (≤10 cm). The density may be underestimated; however, no existing *T. palatum* survey in Hawai`i could confirm this.

Sediment trace metal concentrations and correlations

Landscape development, especially impervious surfaces, may act as a direct runway of contaminants into receiving water bodies. Within this study, seven sediment trace metals (cadmium, chromium, cobalt, copper, nickel, lead, and zinc) and the MPI_8 positively correlated with the impervious surface value, and not with the LDI (Table 4.12). Additionally, the sediment MPI_8 value was highest near two stream mouth sites, He`eia State Park (HSP) and Kāne`ohe Beach Park (KBP) and lowest further away from stream mouths, YWCA and He`eia (H). A previous study in Ala Wai Canal (Honolulu) and Kāne`ohe Stream watershed (Kāne`ohe Bay) found that the suspended particulate matter (SPM) controls most trace element transported by streams (De Carlo et al. 2004). Furthermore, the drainage basins of He`eia, Kea`ahala, Kamo`oali`i, and Kāwā Streams, contribute more than 50% of the total stream discharge into the bay (USAEC 1978). In the previous chapter, the investigation of conventional maps showed Kamo`oali`i along with Kapunahala and Luluku streams were channelised and fed into Kāne`ohe Stream (USGS 1998) (Section 3.4.2). While a suite of metals can be present in high concentrations within sediment, the metal species differentiate in their affiliation to the sediment (Morillo et al., 2002). Within this study, sediment arsenic, chromium, and nickel concentrations had exceeded the sediment quality guidelines (SQG; Figure 4.3). Sediment arsenic concentration exceeded Effect Range-Low (ERL) value at each site, chromium exceeded ERL at KBP, and the nickel concentration exceeded ERL at HSP and YWCA, and exceeded the Effect Range-Median (ERM) value at KBP (Figure 4.3). Three metals have exceeded the SQG and these findings suggest that clam beds nearest the stream mouth have elevated sediment contamination, Further investigation by the State level authorities is suggested (Long et al. 1995).

Research has found that elevated sediment metals were associated with both natural and anthropogenic sources, which is the most likely explanation for the current study results. Sediment metals have also exceeded the SQG in previous studies near the mouth of Kane`ohe Stream than other sites in the bay (Hédouin et al. 2009). Sediment nickel concentrations exceeded the ERM value, and arsenic, chromium, copper exceeded the ERL value (Hédouin et al. 2009). Sediment concentrations of arsenic, cadmium, lead, and zinc, from urban streams were substantially higher than undeveloped areas on O`ahu (Brasher and Wolff 2007). Common anthropogenic sources of arsenic include herbicides, pesticides, and fertilisers, for example, those primarily used in agricultural industries (Appendix 7.1). A common source of nickel and chromium is metal plating. Further sources of nickel include brushwear, brake-lining wear, phosphate fertilisers, and sewage sludges. However, given the volcanic origin of the islands, they also have a naturally high concentration of manganese, nickel, and arsenic (Oki and Brasher 2003). The higher sediment arsenic and nickel at KBP could be due to the channelised Kāne`ohe Stream historically draining the agricultural valley of Kāne`ohe Town, bringing substantial amounts of silt and fertiliser run off to the bay (Pryor 1974). Similarly, sediment arsenic and nickel at HSP, could be temporally released into the waterway with the restoration of lo`i kalo (terraced taro wetland/ponds) and removal of extensive invasive mangroves from He`eia loko i`a, releasing volcanic and past sugarcane agricultural soil. Although banana and sugarcane agriculture were not mapped for past land use in Kāne`ohe Bay (Oki and Brasher 2003), historical and archaeological literature documented extensive irrigated pond field systems and agriculture in Kāne`ohe, Kahalu`u, and He`eia ahupua`a (Handy et al. 1972, Kelly 1975, 1976, Rosendahl 1976). Banana and sugarcane agriculture were raised on earthen dikes, and both kalo (taro) and rice were grown in lo`i (Kelly 1975, 1976, Rosendahl 1976). Elevated soil arsenic can be found on Hawai`i today at former sugar cane plantations at an average of 280 mg kg^{-1} compared with natural background concentrations <20 mg kg^{-1} outside the cultivation areas (Cutler et al. 2013). Soil loss from agricultural fields may contribute to the suspended-sediment load in streams (Oki and Brasher 2003). Given the repeated elevation of sediment metal concentrations, especially exceeding the guidelines, suggests that further investigation by local authorities is required.

The current metal concentrations compared to other Hawai`i, U.S., and global sites, are as follows (Table 4.15). The current sediment arsenic levels were similar to most other O`ahu sites (2.0-19.8 ppm) and the U.S., except Mission Bay, which was higher. These sites also exceeded the ERL value. Previous sediment concentrations of chromium and nickel levels in the bay had reportedly exceeded the sediment quality guidelines (pers. comm. in Hunter et al. 1995). The current sediment chromium levels were slightly higher than previous values in Hawai`i, but lower than the U.S. findings. The sediment chromium values at Honolulu 1996, Maui 2009, and KS 2009 had exceeded the ERL value. The sediment nickel levels in Hawai`i Barbers Beach 1989, Honolulu 1996 and especially Maui 2009 exceeded ERM values, Kāne`ohe Bay exceeded ERM in 1996 and ERL in 2009. The U.S. sediment nickel levels also exceeded both ERL and ERM values.

Clam density correlations with environmental condition

Both *T. palatum* and *C. bella* were the most common clams, the *T. palatum* density was highest at Kāne`ohe Beach Park and *C. bella* density was highest at Waikalua, both sites located at either side of the Kāne`ohe Stream mouth. Neither species had significantly correlated with sediment trace metals. Only *C. bella* density correlated with landscape (LDI) and water metrics (salinity). Similarly, *C. bella* is of the Lucinidae family which are obligate halophiles, only occurring in saltwater (Myhrvold et al. 2014). Although both clams were present either side of the stream mouth, Waikalua had a higher salinity range than Kāne`ohe Beach Park (Table 4.4). The lack of significant correlation between the native clam *T. palatum* and *C. bella* densities with sediment trace metals indicated that they might be less impacted than other clams. In this study, *L. obliquenata* density negatively correlated with six sediment metals (cadmium, chromium, cobalt, copper, nickel, and zinc) and the MPI_8, while *R. philippinarum* density positively correlated with six metals (cadmium, chromium, cobalt, lead, nickel, and zinc) and the MPI_8. Neither clam had densities above 10 clams per m^2.

Within other studies, the *R. philippinarum*, *T. palatum* and *C. bella* were utilised in flat tidal areas as metal biomonitors (Páez-Osuna et al. 1993b, Denton et al. 2006, Ji et al. 2006, Denton and Morrison 2009, Wu et al. 2013). Previous research found *T. palatum* and *C. bella* accumulated similar levels Cr, Pb, and Zn, however, *T. palatum* had higher levels of As and Ni (Denton et al. 2006). In the present study the clam tissues were not analysed for condition or trace metal concentrations due to their low population density. Also, as was noted within the 2010 survey, large intact dead *T. palatum* were observed in this study (Haws et al. 2014). Sediment run-off can negatively affect filter-feeding bivalves. In the past, silt run-off was also observed to smother *R. philippinarum* clams at KBP during high rainfall (Yap 1977). Therefore, both the input of sediment and contamination concentrations could potentially be causing aquatic toxicity. These findings suggests these clams are not viable as biomonitors for the bay.

Table 4.15. Trace metal concentrations in sediment (μg g⁻¹ dry weight) reported from studies in the U.S., O`ahu and Molokai Islands of Hawai`i, this current study (bold), and other tropical locations.

Area	As	Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn	Sample period	Reference
Tomales Bay, U.S.	15.7-20.0	0.37-0.43		206.7-230.0	41.7-46.3	626.7	186.7	20.3-27.0	120	1987	(NOAA 2010)
	11.9	0.26		198	40.2	587		15.8	103	2006	
San Fran. Bay, U.S.	8.8-14.7	0.2-5.2		2.6-170	9.9-48	47.7-1186.7	4.3-110.3	3.6-34.7	133-193	2000	
Mission Bay, U.S.	6.2-49.0	0.11-0.41		40-90.2	19-45	197-485.7	11-25.6	17.2-53.3	67-170	1992	
Barbers Point, O`ahu	5.1	0.22		48.7		203.3	58.3	7.3	47.7	1987	(NOAA 1989a, 2010)
Honolulu Harbour, O`ahu	8.4	0.11		20	24.7	115.7	18	20	50.7	1987	(NOAA 1989a)
	19.8	0.24		136.3	162	402	62	104	23	1996	(NOAA 2010)
Kāne`ohe Bay, O`ahu	17.6	0.04			54	904.7	64.3	18	114	1996	
Kāne`ohe Bay (KB1 5 Sites)	2.0-15.5	0.03	1.5-6.4	4.5-37.4	1.9-11.7	41.2-191.5	4.0-25.5	0.4-2.5	6.2-40.0	2009	(Hédouin et al. 2009)
Kāne`ohe Bay (KS Site)	19.6	0.25	33.4	137	36.8	472.8	153.7	9.7	98.8	2009	
Kāne`ohe Bay, O`ahu	**10.7-21.8**	**0.02-0.04**	**5.2-42.2**	**25-150**	**6.3-30.0**	**231.2-1614.2**	**16.3-208.0**	**3.6-16.8**	**22.4-105.1**	**2014**	**Present study**
Kaunakakai-Kamalo, Molokai	1.6-17.1	0.02-0.16	0.7-5.5	1.8-7.0	0.2-4.3	30.8-301.3	1.8-26.6	0.1-1.7	1.6-53.8	2009	(Hédouin et al. 2009)
Honolua Bay, Maui	4.9-9.5	0.7-1.8	2.6-47.9	13.2-96.4	4.6-16.4	78.1-570.4	9.4-464.4	0.05-0.37	93.8-357.7	2009	
Pago Bay, Guam	0.07-2.39	<0.15		3.27-16.9	0.82-20.3	10.3-533	<0.15-24.2	<0.24-20.5	0.60-89.5		(Denton et al. 2006)
Tanapag Lagoon, Saipan	0.28-7.79	<0.17-1.69		1.42-4.61	0.50-102		<0.20-1.16	0.65-158	2.42-358		(Denton and Morrison 2009)
Stream: Kāne`ohe, O`ahu	11	0.9	42	350	190	0.20%	190	82	470	1998-2000	(De Carlo et al. 2005)
Stream: Luluku, O`ahu	29	0.6	51	470	230	0.13%	190	60	260	1998-2000	
Seven stream sites, O`ahu	6.4	0.57		440	190		280	23	270	1992-2000	(Paul et al. 2012)

4.4.2. *Crassostrea gigas* population indices and trace metal concentrations

This is the first population study of *Crassostrea gigas* along Kāne`ohe Bay, which varied across watershed landscape and water quality parameters. Globally, bivalve density and structure has been linked to population variability (Flach 1996, Gam et al. 2010, Genelt-Yanovskiy et al. 2010), watershed land use (Hale et al. 2004, King et al. 2005), and water quality parameters (Craig 1994, Defeo and de Alava 1995, Carmichael et al. 2004, Gagné et al. 2008). The *C. gigas* density was site-specific and positively associated with the Landscape Development Intensity (LDI) index, as well as salinity, but negatively associated with temperature. This coincided with highest densities at Lilipuna Pier (LP) and Kāne`ohe Pier (KP) within the urban/residential catchments of Ke`ahala and Kāne`ohe respectively. Density was lowest on Waikāne Pier (WP) within the rural catchment of Waikāne. Physiological stress has been measured in *C. gigas* at temperatures of (>20 to 30 ˚C) (Goulletquer et al. 1998), including significant mortality at (32˚C) (Bougrier et al. 1995). Within this study, water temperature range was 20.85-29.12℃, however this was taken when the tide was low andshellfish were exposed.

The biological metrics of oysters were indicative of the surrounding conditions. Past research within New Zealand on *C. gigas* CI metrics (CI *flesh:cv* and CI *flesh:shell*) was able to separate individuals from clean and polluted sites (Roper et al. 1991). Within the same study area *C. gigas* shell density increased with pollution gradient (Pridmore et al. 1990). Within the present study, the *C. gigas* condition index (CI) was negatively associated with tissue arsenic concentration. A CI guideline grade from poor to good was created for C. gigas samples in the past (Westley 1959). The current CI values were compared to this grade but needed to be scaled by 10 x due to difference in CI metrics (Roper et al. 1991). The CI within study from Moku o Lo`e was considered good (>80-100) and those from He`eia loko i`a was poor (≤60). Tissue arsenic was generally highest at He`eia loko i`a (HLI) generally, however this was not significantly different across sites. The sediment arsenic concentration however, was significantly elevated at the adjacent He`eia State Park. Although the uptake of soluble and sediment-bound arsenic resulted in low tissue accumulation, the cytological effects have been noticed in oysters exposed to sediment-bound arsenic and moreover to soluble arsenic (Ettajani et al. 1996). Other *C. gigas* CI findings have been associated with water chemistry, nutrition, reproductive and size-related differences, suspended particulate matter (SPM), water depth, pollutants, and other organisms associated with oysters (Brown and Hartwick 1988, Pridmore et al. 1990, Roper et al. 1991, Kaufmann et al. 1994, Mason and Nell 1995).

Trace metal concentrations of *C. gigas* tissue samples were associated with catchment landscape development and inner estuary habitat type. The *C. gigas* tissue lead concentrations were positively associated with the LDI index and were particularly elevated at the LP site and adjacent inner island Moku o Lo`e (M) and the southern Waikalua loko i`a (WLI). Conversely, the tissue manganese varied across habitat types, and was lowest at M and elevated at both HLI and WLI. Similarly, the previous trace metal examination of *C. gigas* across the bay, showed elevated levels near stream mouths within the urbanised sector (Hunter et al. 1995). In particular, tissue lead concentration was also elevated at Makani Kai, followed by Lilipuna, and lowest at Waikāne (Hunter et al. 1995). Tissue manganese did not correlate with landscape development, and may be naturally occuring. When the island (lowest score) was excluded from the analysis, there was no differences between piers and loko i`a walls. High concentrations of manganese in particular is due to volcanoes forming the Hawaiian Islands (Oki and Brasher 2003). It is widely acknowledged that anthropogenic lead dominates the lead distribution of the ocean, while the oceanic distribution of manganese requires further information of the mechanisms controlling its distribution (Boyle et al. 2005). Common anthropogenic sources of lead sources were mentioned above (Appendix 7.1).

The current converted wet weight trace metal concentration in *C. gigas* (µg g^{-1} soft tissue) did not exceeded human consumption guidelines (Table 4.16). *C. gigas* has been shown to be a more suitable as an indicator of low and moderate, rather than high concentrations of contamination because it regulates the accumulation of certain metals, including copper, lead, and zinc (Shulkin et al. 2003). The *C. gigas* tissue trace metals concentrations were compared to various studies (Table 4.17). Interspecies comparisons are discussed here with caution because of the variability in accumulation rates of metals among some bivalve species. The current *C. gigas* tissue concentrations of arsenic, copper, and zinc were higher than previous Kāne`ohe Bay findings. *C. gigas* arsenic was also higher than O`ahu and the U.S. findings, but tissue copper, and zinc, were lower than previous U.S. findings. The tissue lead concentrations were lower than previous findings in the bay and global sites. Tissue manganese concentration was similar to *C. gigas* reported from Hong Kong (H.K.), and lower than *C. gigas* in the U.S. *C. gigas* tissue manganese concentration has not been previously examined, but it was measured in *Ostrea* sp., which was lower in concentration than the current *C. gigas* concentration

Table 4.16. Wet weight-converted *C. gigas* trace metal concentration (µg g^{-1} soft tissue ±S.E.) to compare with the human consumption guidance level (wet weight µg g^{-1} soft tissue) (U.S.FDA 1993), and no value (n.v.).

	As	Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn
All sites	1.86-7.14	0.07-0.18	0.09-0.18	0.14-0.77	51.2-176.49	3.19-10.07	0.19-0.54	0.02-0.10	69.88-406.50
Guidance level	86	4	n.v.	13	n.v.	n.v.	80	1.7	n.v.

Table 4.17. Tissue trace metal concentrations in *C. gigas* and *Ostrea* species ($\mu g\ g^{-1}$ dry weight) of this current study (bold) and from various other studies.

Area	As	Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn	Sampling Period	Reference
C. gigas											
Tamar River, AUS		4-135		1-37	200-1700			0-135	2000-14000	1973	(Ayling 1974)
Helford River (tidal estuary), U.K.		6			273				1640	1971	(Thornton et al. 1975)
Colne Estuary, U.K.		4			110				1540	1970	
Poole Hbr, U.K.		4			155				1190	1970	
Deep Bay, H.K.		3.8		103	468	40		10	913	1977	(Wong et al. 1981)
Redwood Creek, U.S.	5.8-9.6	46-62		<7.5-<9.3	1241-1680	49-62	3.9-6.5	3.9-7.1	4514-6219	1975	(Okazaki and Panietz 1981)
Tomales Bay, U.S.	5.6-10.0	7.0-12.0		<5.4-<8.1	54-155	19-158	2.2-<3.0	<2.7-<3.3	286-791	1975	
Tamar Estuary, AUS		1-23			10-380			1-30	200-7800	1974-1975	(Thomson 1982)
Manukau Hbr, NZ					178.8-1218.8				970.2-4145.6	1988	(Pridmore et al. 1990)
Kāne`ohe Bay, MHI	7.2-13.9	0.5-0.8		1.8-11.5	151-525			0.04-2.4	422-1268	1991	(Hunter et al. 1995)
Kāne`ohe Bay	**7-30**	**0.3-0.8**	**0-1**	**1-2**	**284-832**	**18-47**	**1-2**	**0.2-0.4**	**488-1594**	**2014**	**Present study**
***Ostrea.* sp**											
Barbers Point, MHI	16.0	1.2		1.9	1200	17.1	2.5	2.3	790	1986-1988 Mean	(NOAA 1989a, 2010)
Honolulu Hbr, MHI	18.0	0.8		2.3	1400	12.9	1.8	4.9	840	1986-1988 Mean	(NOAA 1989a)
Kauai, MHI	8.0	0.4		8.2	700		20	0.8	620	1986-1988 Mean	
Barbers Point	22.6	0.8		1.4	1567	12.7	1.8	0.7	783.3	1991	(NOAA 2010)
	1.7	0.9		5.6	1700	34.6	9.6	1.4	3800	1994	
	10.9	0.5		1.2	1610	18.1	1.3	5.3	742	2002	
Honolulu Hbr	19	0.3		0.7	2400	35.2	2.7	4.7	1066.7	1990	
	15.5	0.3		3.4	3100	24.2	3.1	5.5	1000	1994	
	13.5	2.3		2.5	2280	12	1.3	1.6	909	2002	
	9.6	0.4		3.9	2050	36.6	3.1	6.0	988	2006	
Kāne`ohe Bay	12.1	0.5		0.0	665	24.4	0.6	0.2	1012	1996	
	8.8	0.5		2.2	884	27.6	2.1	0.6	1400	1998	
	14.4	0.7		2.2	1150	32.7	1.8	0.8	1590	2002	
	10.4	0.7		1.6	414	22	1.3	0.7	1410	2006	
	11.6	0.5		2.0	779	21.1	2.4	0.5	1560	2010	

4.4.3. Socio-cultural and shellfish ecological findings to better guide management

Within the evaluation of favoured and targeted fishery resources, shellfish were infrequently mentioned (Figure 3.4), because they were closed from harvest since the late 1960s. The culturing of *C. gigas* in one loko i`a in the northern sector was perceived to have increased over time. The natural (or wild) populations of clams and oysters perceived to have declined over time or were no longer available (Table 3.5-3.6, Chapter 3). Considering the long-term prohibition of shellfish populations from recreational take, it was likely the current density is indicative of natural predation and environmental condition. There was no observed harvesting of clams or any shellfish in this current survey, nor was it observed when the fishery first closed (Yap 1977). The current ecological results of clam density, and trace metal levels in sediment of clam beds sites, suggest that further monitoring is required, and that further management measures are required.

The perceived decline or degradation of aquatic life by participants was associated with the degraded condition of landscape. Land-based development and direct freshwater input can influence nutrient and sediment loads, into coastal and estuarine bodies, which can cause eutrophication problems (Paerl et al. 1998, Bricker et al. 1999, Laws and Ferentinos 2003, Bricker et al. 2008, Brush 2009). According to participants in the present study, the catchment was poor and fair due to channel erosion, declined water clarity, water diversion, landscape management, land run-off, and the lo`i kalo systems that are not yet functioning (Section 3.5). Within the southern-sector, land run-off and sewer were two of the main poor indicators, which reportedly affects aquatic species, including shellfish. Similar with past survey studies in Hawai`i, recreational fishers were most concerned by the impacts of stream diversions, sediment and pollutant runoff from urbanisation and deforestation, and overfishing (Lowe 1995). Within this study, the elevated sediment nickel and tissue lead concentration were likely of anthropogenic sources, and were elevated within urbanised catchments.

The development of landscape in the bay has affected the traditional system of integrated management, an important factor in estuarine ecology. The participants' evaluation of main impacts to the site of reference, and the catchment score, agreed with the quantified landscape indices (LDI and impervious surface value, Table 3.13, Section 3.7). Good and excellent catchment scores were associated with the areas of active/restored integrated management systems– for example functioning lo`i kalo, mauka makai, less developed landscape, freshwater quality (Section 3.5).

Within this study, the sediment arsenic concentrations exceeded the sediment quality guideline and were highest at both stream mouth sites. In addition, the landscape indices correlated with sediment and oyster concentrations of particular trace metals (Section 4.3.7). Taking heed of indigenous-practices that worked with the local streams network, could inform local management. Traditional extensive kalo in Kahalu`u were mentioned by participants in the socio-cultural chapter of this study.

Kalo was one of the main crops grown on O`ahu prior to commercial agriculture (Kelly 1975, Oki and Brasher 2003). In traditional ahupua`a systems, the activities that occur upland in the kalo fields affected what happened below in the fishpond (Hufana 2014). Extensive efforts in lo`i kalo restoration is underway in Kāne`ohe Bay. Recent research in Palau, has shown that taro fields have the capacity to trap up to 90% of sediments (Koshiba et al. 2013), which may reduce sediment-bound trace metal concentrations.

Wider system management of estuaries would benefit from a mountain-to-sea approach. There are many cumulative impacts in the bay, including the loss of taro fields, and increase in commercial agriculture and the initial soil erosion, and the increase in landscape development. Both the Local Practitioners and Specialists (LPS) and some of the Recreational Participants (RP) highlighted this interconnectedness of land-to-sea and people-to-environment (e.g. mauka makai, integrated function, mālama the place, and traditional ahupua`a management). Knowledge system of Indigenous Hawaiians and organisations currently guide and lead the process of restoring ecological systems, with support from State agencies and the community (Section 3.44). Impacts of particulate nutrients on coastal ecosystems will depend on how efficiently SPM is retained in nearshore areas, and the timing and degree of transformation to reactive dissolved forms (Hoover and Mackenzie 2009). Issues in shellfish management have been a long-standing problem in Hawai`i, therefore, management of waterway and terrestrial input into these systems is important.

4.4.4. Conclusion

It is concluded that benthic infaunal shellfish density in Kāne`ohe Bay has probably been more impacted by anthropogenic conditions compared with the surface dwelling Pacific oyster, *Crassostrea gigas*. The density of bio-monitors *Tellina palatum* and *Ctena bella*, were higher than other clams, and both densities were independent of sediment contamination. However, neither exceeded a site abundance of 30 clams per m^2.

The clam-bed sediment contamination concentrations exceeded the Sediment Quality Guidelines and were comparable to findings in the U.S. This requires further investigation by local authorities. Sediment concentrations were especially elevated near stream mouth input. In other studies, suspended sediment material was found to be major sources of contamination within O`ahu rivers.

C. gigas condition was indicative of environmental condition, with lower condition index associated with elevated tissue arsenic concentration. Also *C. gigas* tissue lead concentrations were positively associated with landscape indices. Soft tissue lead concentration was significantly different between sites, and manganese between habitat types. *C. gigas* trace metals were within the limits of human safety guidelines, however the condition index was poor at high arsenic sites. Compared to past studies in Kāne`ohe Bay, concentrations of soft tissue arsenic, copper, and zinc, have increased over time, and soft tissue arsenic was higher than *C. gigas* from other O`ahu sites and the U.S. (Table 4.17).

The overall finding of both Chapter 3 and 4 chapter supports the view that estuaries are interconnected with their surrounding landscape, and anthropogenic input enters via waterways. Participants' perceived environmental changes correlated significantly with landscape values (LDI and impervious surface values). Land run-off was one of the main poor indicators, which sewer and pollutant input in the southern-sector reportedly benthic species. Landscape indices correlated with sediment and oyster concentrations of trace metals. Furthermore, the northern loko i`a has been validated as a commercial aquaculture operation, while the southern sites have water quality concerns (Department of Health 2014). This research not only supports land-to-sea evaluation using multiple values and indices, but also supports the restoration of the ancient ahupua`a system of Hawai`i, which could lead towards better management.

This current methodology could be utilised to further monitor and assess changes over time with the current cultural-ecological restoration in the bay (See section 4.4.3.). The restoration of these integrated systems would benefit waterway quality and sediment retention (personal communication 2014), as mentioned by multiple participants (Section 3.6). Impacts of particulate nutrients on coastal ecosystems will depend on how efficiently SPM is retained in nearshore areas, and the timing and degree of transformation to reactive dissolved forms (Hoover and Mackenzie 2009). Recent research in Palau, supports current efforts, which have shown that taro fields have the capacity to trap up to 90% of sediments (Koshiba et al. 2013). Issues in shellfish management have been a long-standing problem in Hawai`i, therefore, a more holistic approach to management is important.

Chapter 5 Socio-cultural values of shellfisheries in Aotearoa New Zealand

5.1. Introduction

In Aotearoa New Zealand, estuaries have shaped major tribal homelands, genealogical ties, towns, and cities. Sustenance, cultural wellbeing, recreation, commercial activities, and societal traditions, were sourced here (Tau et al. 1992, Harmsworth 1997, Clough 2013, Thrush et al. 2013). In Te Wai Pounamu, South Island, estuaries, coastal zones and their resources were part of the seasonal inter-tribal relations and economics (Mules 2007, Williams 2016). Traditional socio-ecological knowledge was both intimate and extensive, transmitted within oral methodologies in weaving together the strands of whole systems. This knowledge was embodied in and by whakapapa, pepeha/ancestral sayings, and geo-spatial references (Best 1929, Beattie 1994, Williams 2001, Wehi 2009, Harmsworth and Awatere 2013), holding both wider and local relevance. The 'Taiaroa Map' illustrated within Beattie (1994) illustrates the intimate and extensive cultural-ecological knowledge of Ngāi Tahu throughout Te Wai Pounamu, where numerous tributaries were named. For example, the major focal shellfish species in this current study, the tuangi/tuaki *Austrovenus stutchburyi* recited within the whakapapa of Waitaha/Canterbury waterways (Niupepa 1894) (Figure 5.1). Whakapapa encapsulated and emphasised the familial connection of Māori with the environment and its resources (Tomlins-Jahnke and Forster 2015); it is the shaping of ecology with culture and vice versa.

Accumulated and held across generations, cultural-ecological knowledge shaped local and tribal identity, wellbeing and, environmental ethos (Tau et al. 1992, Mules 2007). Spiritual qualities guided resource use through an elaborate system of ritenga (rules/rights), and included the guiding values and concepts of kaitiakitanga, tapu, mauri, rahui, mana, noa, and wairua (Harmsworth and Tipa 2006). Fishery activities intertwined with environmental accountability were the responsibilities and rights of collectives, local groups (rather than individual) and, specifically iwi, Mana whenua (Best 1929, Guth 2001, Williams 2004). Of primacy to environmental management was the reciprocal relationship between tangata and whenua, which remains applicable today.

Despite the long-held relationship between Tangata whenua and the environment of Aotearoa, and Māori participation in the Ministry for the Environment national environmental indicator programme (Harmsworth and Tipa 2006), estuarine food safety and management from a Māori worldview is not yet evaluated. The socio-cultural values of estuaries are integral to the effective overall management and accountability of anthropogenic activities. In particular, kaitiakitanga is concerned with maintaining the health of the environment for future generations (Tomlins-Jahnke and Forster 2015).

Such activities ensure that ancestral landscapes shape Māori communities, cultural identity and develop a sense of place (Tomlins-Jahnke and Forster 2015).

...ko Rangiroa,	*The Long Horizon*
nana ko Tutumai ao,	*Summer haze upon the beach*
nana a Haehaeone,	*The Lacerated Sands*
nana Matakurae,	*The Headland*
nana ko Tumanahune,	*The Hinterland (McKenzie Basin)*
nana ko Takoi otua,	*The Peaks of the Hinterland*
nana Taputekaehe,	*The murmuring tide*
nana ko te Moeanu,	*The Sandfish*
nana ko Hineroriki,	*Northerly Wind*
nana ko Hinerotea,	*Nor-westerly winds*
nana ko te Kuharu	*Gari strangeri and Tellina glabrella*
nana ko Taiari,	*River (or pipi taiari* Antalis nana)*
nana ko te Roroa,	*Resania Lanceolota/Paphies ventricosa*
nana ko Te Tuaki,	*Chione stutchburyi (Austrovenus stutchburyi*)*
nana ko te Whetiko,	*Amphibola crenata*
nana ko te Kaeha,	*The Kelp Fish*
nana ko Te Orooro,	*Movement of the Tide*
nana ko te Akiwai,	*and Pounding of the Water*
nana ko Tumataenuku,	*Against the Earth*
nana ko Tumata-araki...	*Against the Heavens...*

Figure 5.1. A genealogical reference of waterways and shellfish species in the South Island (Niupepa 1894), translated by T.M. Tau (Personal communications 2015) and additional names from this current research*. The additional names were sourced from Māori excavation research and Ngā pepeha a ngā tipuna/ancestral sayings (Dawson and Yaldwyn 1952, Mead and Grove 2004).

As in Hawai`i (Section 3.1), current environmental management in Aotearoa is compartmentalised into ‘resource management units’. In the South Island, the land-to-sea connectivity is captured in the Ngāi Tahu philosophy ‘ki uta ki tai’ and guides contemporary management practices by local hapū bodies and regional councils (KTKO 2005, Hepburn et al. 2010, Canterbury Water 2012, Council 2013, Mahaanui Kura Taiao Ltd 2013). As illustrated in the whakapapa above (Figure 5.1), the Indigenous perspective of ecology by Ngāi Tahu interconnects species (e.g. tuangi) with place-based environmental feastures, including the local winds and local waterways; the complete system. While systems connectivity is well-recognised in scientific research, current policies and management do not effectively account for or reflect this Ngāi Tahu philosophy (Hart and Bryan 2008, Phillips et al. 2010, Schiel and Howard-Williams 2016). Many of the nation's estuaries and coastal sites have poor water quality, leading to the restriction of human contact or food consumption over long periods of time, for example, the Tauranga and Waihī estuaries (Parliamentary Commissioner for the Environment NZ 2012). Numerous kaitiaki and local Māori members have voiced concerns over fisheries decline and degraded environmental conditions (Harmsworth et al. 2011, Dick et al. 2012, McCarthy et al. 2014). Furthermore, the New Zealand biotoxin monitoring programme fails to provide a holistic approach to shellfish safety (Turner et al. 2005).

To incorporate a systems approach, it is necessary to focus on the relationship of people within the environment system, which is often captured in Indigenous Knowledge, or Traditional Ecological Knowledge (TEK). Interweaving science and social sciences (including community engagement, Māori values, and policy) is a fundamental component within integrated catchment management (Phillips et al. 2010, Fenemor et al. 2011, Hickey-Elliott 2014). More holistic frameworks have been developed to incorporate TEK and Cultural Health Indicators (CHI) towards the management of waterways (Tipa and Teirney 2003, Pauling 2008), marine systems (Bird et al. 2009, Moller et al. 2009a, Dick et al. 2012, Schweikert et al. 2013, McCarthy et al. 2014) and estuaries, including those of this current study (Rāpaki, Koukourārata, and the Avon-Heathcote estuary) (Pauling et al. 2007, Pauling 2008, Hepburn et al. 2011, Lang et al. 2012, Mudunaivalu 2013). Local socio-cultural indicator frameworks, such as the CHI and Atua frameworks (see Awatere and Harmsworth 2014), and included the State of the Takiwā framework (Pauling et al. 2007) and iwi estuarine indicators (Walker 2009) in Canterbury and Nelson, respectively. The socio-cultural values of Māori and non-Māori within the estuarine shellfish environment have not been investigated. This current study compliments existing approaches by interviewing participants from a range of cultural-affiliations, including Mana whenua, to evaluate local perceptions of the state of the environment, and what is required to to support their interaction with place, including food safety and best management practices.

A multiple methods approach is used in this study to combine scientific and socio-cultural knowledge in the assessment of estuarine and shellfish bed conditions across in Waitaha. This chapter focusses on the socio-cultural values and knowledge for each of the four areas according to Recreational Participants (RP) and Local Practitioners and Specialists (LPS), who affiliate as local residents, estuarine-visitors and tourists, fishers (recreational/commercial/customary), environmentalists/ecologist specialist/researchers, Tangata whenua, and Mana whenua. Chapter 6 evaluates shellfish ecological values and indicators (including landscape values), and the final discussion (Chapter 7) combines the findings from both Chapters 5 and 6 towards best management practices in Waitaha.

5.1.1. Waitaha estuaries: Mana whenua and landscape.

The four study estuaries, Rakahuri/Ashley-Saltwater Creek Estuary, the Avon-Heathcote Estuary, Rāpaki Bay and Koukourārata (Figure 5.2) are located within Ngā Pākihi-Whakatakataka-o-Waitaha, the modern-day Canterbury. Each is culturally important to local hapū of Ngāi Tahu Whānui, alongside cultural values of local Cantabrians, and the national and international value to people and wildlife. Previous research has provided thorough environmental descriptions (Marsden and Pilkington 1995, McConway 2008, Adkins 2012) and cultural narrative for these areas (Tau et al. 1992, Mudunaivalu 2013). This section provides a brief background for each of the estuarine districts, including who the Mana whenua of these estuarine areas is and mahinga kai knowledge in these areas. Mahinga kai generally refer to 'places at which food (and other commodities) were extracted or produced' (Anderson 1998), and 'food-gathering places' (Beattie 1994)

Ngāi Tūāhuriri are Mana whenua of Rakahuri/Ashley-Saltwater Creek Estuary, with traditional mahinga kai areas throughout the estuary and fishing easements reserves along the river. This estuary is located within the Waimakariri District of North Canterbury is (Figure 5.2-5.3), and is a semi-enclosed embayment, with a free connection to the sea at one end and at the other end are several freshwater sources (Bolton-Ritchie 2016). The Rakahuri River, Saltwater Creek, and Taranaki Creek are the main catchments into this estuary; the latter two are tidal fed, with channelised waterway input into Taranaki Creek, and includes urban storm water (Bolton-Ritchie 2016). Figures 5.2 and 5.3 illustrate that the present land use is predominantly high-producing exotic grassland and short-rotation cropland, for high-intensity of agriculture/rural activities.

The Avon-Heathcote Estuary/Ihutai (AH) is Canterbury's largest semi-enclosed shallow estuary (Environment Canterbury 2007), and is located along the east-coast section of Ōtautahi, Christchurch City. Both Ngāi Tūāhuriri and Ngāi Tahu have cultural associations to AH - including Te Ihutai reserve, Ōtākaro/Avon River, and Ōpāwaho/Heathcote River (Tau et al. 1992, Tau 2003). Historically, Te Ihutai reserve was part of a larger fishery used by a number of hapū and whānau within Ngāi Tahu, while owners were those of Kaiāpoi Reserve (Tau et al. 1992). The Avon and Heathcote Rivers are the main waterway catchments, both predominantly built-up landscapes (residential and urban settlement) (Figure 5.2-5.3). The estuary has received past storm water input from industrial catchment and (pre-2010) sewage discharge (Batcheler et al. 2009, McMurtrie 2010, 2012).

Both Rāpaki and Koukourārata/Port Levy (Figure 5.2-5.3) areas are part of the wider basin of the Lyttelton Harbour, within Te Pātaka a Rākaihautū, Banks Peninsula (Tau et al. 1992). Ngāti Wheke are Mana whenua of Rāpaki, this Pā was founded by Te Rakiwhakaputa and became a central mahinga kai site due to the abundance of natural resources within Whakaraupō, Lyttelton Harbour (Tau et al.

1992). Ngāti Huikai are Mana whenua of Koukourārata, and this area was traditionally occupied in three main centres: Koukourārata, Puari, and Kai-Tara. Following the fall of Kaiāpoi Pā, both Koukourārata and Puari became the main centres of Ngāi Tahu activity in Waitaha (Tau et al. 1992). In 1849, the Port Levy Purchase saw local iwi confined to a small reserve - Koukourārata Māori Reserve - on the eastern side of the bay (Tau et al. 1992). The current shellfish sites 'Koukourārata rocky' and 'Koukourārata Pā' are adjacent to the catchments of Puteki and Pā, respectively (Figure 5.6).

Many of the bays accessible by road now have urbanised areas, and with increasing urbanisation comes increasing volumes of wastewater, which is discharged into Lyttelton harbour through outfalls off Diamond Harbour, Governors Bay, and Lyttelton (Bolton-Ritchie 2011). Households within more rural areas rely on septic tanks or on-site systems for sewage treatment also (Bolton-Ritchie 2011). The combined catchments of Witch Hill-Māori Gardens feeds into Rāpaki Bay, and comprised of low producing grassland, and small amount of exotic harvested forest, broadwood exotic forest, and gorse and/or broom (Figure 5.2-5.3). Puteki was predominantly high producing exotic grassland, and Pā was a mix of high producing exotic grassland, with manuka and/or kanuka, and broadleaved indigenous hardwoods (Figure 5.2-5.3).

5.1.2. Historical changes

Traditionally, all four estuaries in this study (Figure 5.2) supported important mahinga kai as part of the traditional connection with place. Today, traditional practices are undertaken to a lesser extent (indeed, some no longer exist) due to landscape degradation of land/waterway boundaries and loss through Crown breaches to the Treaty of Waitangi during land purchases (Waitangi Tribunal 1995, Parliamentary Counsel Office 1998). Over time, mahinga kai have been degraded or diminished due to Crown aqcuisition of iwi land and waterway and the anthropogenic changes to catchments, inner estuaries and waterways, and reserves (e.g. the Fenton Reserves) (Tau et al. 1992, Parliamentary Counsel Office 1998). Note that Te Ihutai reserve is a specific area located within the Avon-Heathcote Estuary (Tau et al. 1992) and the Fenton reserves includes those in Rakahuri/Ashley River-Saltwater Creek estuary as mentioned in the Settlement Act see Schedule 115 (Parliamentary Counsel Office 1998). Such degradation to Te Ihutai included (but was not limited to,) the discharge of sewage (Tau et al. 1992). Despite this degradation, the recreational and natural values of each area persist, with some sites being commercially utilised (Boyd 2010, Fisher and Vallance 2010).

Changes in the use of wetlands and catchments have impacted traditional sites and fishing reserves created by the Crown. Historically, North Canterbury reserves and Christchurch wetlands were all drained (Tau et al. 1992, Waitangi Tribunal 1995). Within North Canterbury, the fishing reserve became landlocked (Tau et al. 1992, Waitangi Tribunal 1995); fish were affected by the hydrological regime, passage depth for migratory species became constrained (Mosley 2011). Within Christchurch the traditional mahinga kai sites utilised by Ngāi Tahu were destroyed (Tau et al. 1992, Waitangi Tribunal 1995) and the fishing reserve, Te Ihutai was later compulsory acquired under the Public Works Acr (1928) in 1956, as part of a site for the sewerage scheme by the Christchurch Drainage Board (Tau et al. 1992).

This input of sewage (including treated) violated the principals of mahinga kai gathering and management, but local Māori were not consulted regarding the plant and its effects on the Estuary (Boyd 2010). Mahinga kai collection ceased and a rāhui (a restriction on the access to or use of an area or resource by unauthorised persons) was placed on the estuary by Ngāi Tahu (Deely 1992). Similarly, the whole of Te Whakaraupō/Lyttelton Harbour was once used as mahinga kai; however, by the early 1990s very little food was gathered from the beach or harbour due to effluent discharges and sedimentation (Tau et al. 1992). Due to local Mana whenua concerns at Rāpaki Bay (located within Te Whakaraupō) and Koukourārata/Port Levy (connects to Te Whakaraupō), mātaitai reserves were established to recognise the cultural importance of the sites and to provide food gathering areas (DOC 2014). Such mātaitai reserves, along with taiāpure and temporary closures, are Area Management Tools. Although mātaitai and taiāpure are not marine protected areas, their management provisions may qualify as providing marine protection (DOC 2014). In December 1998, Rāpaki Bay Mātaitai Reserve was the first of its kind to be established in New Zealand, the bylaws of which prohibit the taking or possession of whairepo (skale and ray), pāua (Abalone - *Haliotis* spp), or seaweed, and state that no person shall in any one day take or possess more than 50 cockles and/or 50 pipi from the site (NZG 2000). In December 2000, the Koukourārata Mātaitai Reserve was the second to be established the bylaw of which states that no person may take any or be in possession of any cockles (*Austrovenus stutchburyi*) taken from that area (NZG 2001). These regulations are still in effect, and in addition, the (now named) Port Levy Mātaitai Reserve bylaw states that cockles can only be taken from within the reserve on any Saturday or Sunday during the month of September by persons possessing a gathering permit from the local Kaitiaki (MPI 2016). Furthermore, there are closed areas where all fishing is prohibited within Whakaraupō/Lyttelton and Koukourārata/Port Levy (MPI 2016).

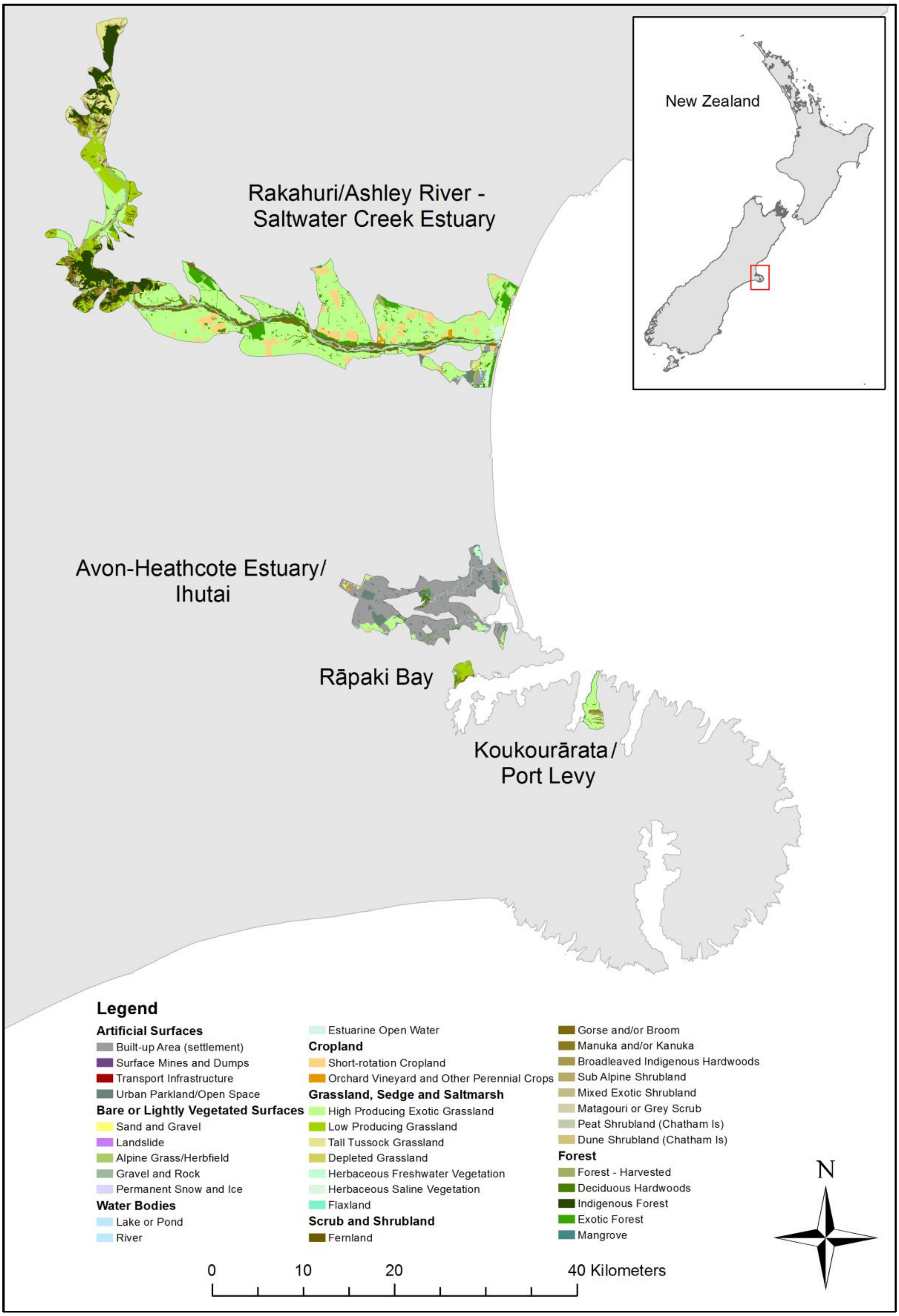


Figure 5.2. Map of the Canterbury study area catchments and the location in New Zealand (inset), along with the most recent (2012) land cover data base classification(LRIS 2012, Canterbury Maps 2015, LINZ 2015).

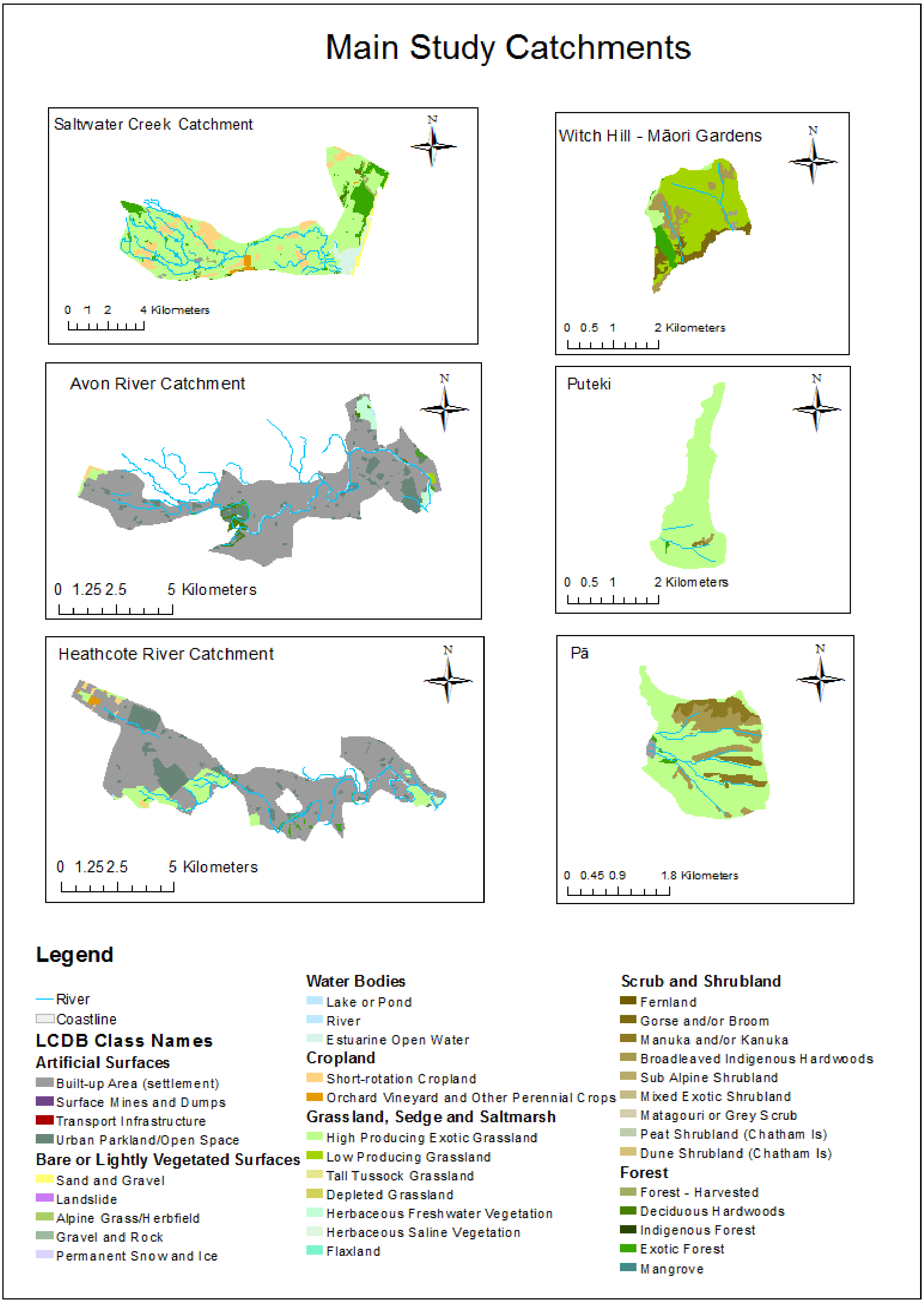


Figure 5.3. The 2012 land cover data base (LCDB) classification of the study catchments: Saltwater Creek, Avon River, Heathcote River, Witch-Hill Māori Garden (Rāpaki Bay), Puteki and Pā (Koukourārata) (LRIS 2012, Canterbury Maps 2015, LINZ 2015).

5.1.2. Objectives

The chapter objective was to evaluate the socio-cultural values of four Canterbury estuaries. The specific objectives of this chapter were to:

1. Identify who visits these estuaries and examine how the perceptions of participants differed for Local Practitioners and Specialists (LPS) and Recreational Participants (RP), and according to cultural affiliation, experience (years), and location (site/area).
2. Evaluate the traditional uses, cultural values, and participants' main activities. If relevant, to determine participants' favoured and targeted fishery/other living resources, and record any perceived changes in abundance over time.
3. Evaluate the perceived environmental condition of site and catchment and if anymain changes have occurred over time
4. Investigate if there were environmental indicators associated with activities and values.
5. Identify what current management and practices were conducted by participants and if management was regarded as effective.

These findings are further combined with the shellfish ecological findings (Chapter 6) to better inform fisheries management decisions.

5.2. Methods

This section provides the research methodology unique to the social-cultural and landscape research in Canterbury. Chapter 2 provides the overall interview methodology and analysis, and general statistics.

5.2.1. Site Selection

Both the socio-cultural survey and shellfish surveys were conducted across four Waitaha/Canterbury estuaries, including Rakahuri/Ashley River-Saltwater Creek Estuary, Avon-Heathcote Estuary, Rāpaki Bay, and Koukourārata (Table 5.2). Each estuary is socially, culturally, and ecologically valued. The site criteria for carrying out socio-cultural surveys included: access; the presence of people within the area to interview/survey, fishery and recreational areas; and where possible, boaters and sailors. The survey information from participants was grouped into demographic and participant group to provide anonymity (LPS/RP). Previous socio-cultural surveys in these areas included: social use reviews and surveys (Boyd 2010, Fisher and Vallance 2010), Ngāi Tahu resource management (Waitangi Tribunal 1987, Tau et al. 1992, Waitangi Tribunal 1992, 1995), and combined cultural and environmental health monitoring (Pauling et al. 2007, Lang et al. 2012).

5.2.2. Socio-cultural survey

The survey methodology was given in Section 2.2. The interviews were all conducted in English, and many participants referred to Ngāi Tahu or Māori terms and concepts. It is important to realise the distinct and diverse range of views and values from within groups of Tangata whenua, Pākehā, and other New Zealanders (Harmsworth 2005). Due to small numbers of people outdoors during winter 2014 meant that most of the RP interviews were conducted, with the assistance of a summer biology student, over the summer period of 2014/2015. The goal was to gather at least 100 surveys across the areas, and in particular ensure an even number of RP at each area.

The Recreational Participants (RP) comprised of beach-goers, fisher/harvesters, yachters/boaters, and kayakers. The RP were intercepted or met at a range of locations within each area. Local Practitioners and Specialists (LPS) consisted of local authority members, environmental practitioners, environmental scientists/ecologists, environmental program managers, gatherers/fishers, and residents who had long-term experience within the area. Engagement, discussions, and interviews were done face to face using a voice recorder. Following the interview transcribing, and review process, mixed methodology analysis was undertaken, as described in Chapter 2 (see Section 2.3.).

5.2.3. Statistical Analysis

Anonymous quantitative information from interviews and questionnaires (n=106) was entered into Microsoft™ Excel. These were organised into location (R-SC, AH, R, K), participant groups RP (n=83) and LPS (n=23), cultural affiliations, and experience (years). Cultural affiliations were specifically grouped into Ngāi Tahu (n=20), Māori/non-Ngāi Tahu (n=10), New Zealand born citizens and long-term residents who were not Māori, i.e. European (NZC, n=69) and Cook Island Māori (n=2); and visitors/tourists (n=5). Participant experience was grouped into either <10 to <20 (n=67) and 20 to 30 years (n=39). Four time periods were used within the correlation analyses (<5/10/20/30 years). It is further noted here that some participants had a longer experience period in their respective area, however these reference points were made to provide comparative time periods between participants. All statistical analyses were done using Statistica Software Version 13.

The Fisher's exact test was used to analyse the nominal answers relating to main activities, environmental condition, and management. These were compared across participant group, location, or experience. The assumption of sample size (cell count) was not met, and the independence assumption was met, supporting the use of Fisher's exact test.

The environmental indices provided by participants did not meet normality. These were compared by Mann-Whitney U (participant group and experience) and the Kruskal Wallis test (location and cultural affiliation). The environmental indices grouped by similarity for instance water condition was the combined score of water quality and flow. An environmental index (good-poor) was also calculated and compared using these tests.

A correlation analysis was used to analyse the relationship between perceived fishery resources and participant experiences. The perceived fishery variables and the landscape indices were non-normally distributed, as confirmed by the Shapiro-Wilk test. Various transformations did not improve normality; therefore, the Spearman rank analysis was used. Statistical significance was set at $\alpha=0.05$. A problem with multiple variable correlations is that there could be a high number of false discovery rates (FDR) (McDonald 2009). The Benjamini-Hochberg procedure controlled for this, with FDR of 5%, specific methods given in Chapter 2.

5.3. Results

5.3.1. Participant demographics

A total of 83 Recreational Practitioners (RP) and 23 Local Practitioners and Specialists (LPS) were interviewed during this study in four estuarine systems across Canterbury. The interviews included a wide age range from ≥18-80 years old, and there was a higher number of male participants (61%) than female (37%) participants. A similar proportion of participants were surveyed across all estuaries (Table 5.2).Three of the RP surveys were returned from the more remote locations by mail; two fromKoukourārata (K) and one from Rakahuri/Saltwater Creek Estuary (R-SC); and two people had agreed to a telephone -survey from the Avon-Heathcote Estuary (AH) and R-SC.

Most LPS individuals were culturally affiliated to Ngāi Tahu (74%), and few affiliated as New Zealander/NZ European/Pākehā (17%), and European (9%). Many RP were New Zealand European/Pākehā (72%), NZ Māori (12%), Ngāi Tahu (7%), NZ-based Pacific Islander (4%), visitors – French, Chinese, British (5%)..Ngāi Tahu participants affiliated with the iwi of Ngāi Tahu, Waitaha, Ngāti Mamoe, as well as non-Māori ethnicity. The hapū affiliations, alongside and including hapū affiliations Ngāi Tūāhuriri, Ngāti Huikai, Ngāti Wheke, as well as associated with another iwi, Rangitāne, Ngāti Mutunga, Ngāpuhi, and Irish. Māori affiliated as Ngāti Hangara, Te Atiawa, Tainui, Ngāti Hine, Ngāti Rehia, as well as Welsh and Scottish affiliations. The cultural affiliation of NZ Europeans and Europeans included South African, Serbian, Indian, Welsh, Pākehā and New Zealander.

5.3.2. Current and traditional values of Local Practitioners and Specialists

The value of each estuary within Ngā Pākihi-Whakatakataka-o-Waitaha was discussed with the Local Practitioners and Specialists (LPS), which highlighted their relationship with each place. Consistently, local Mana whenua were referred to by Ngāi Tahu and New Zealand Citizen (NZC) LPS for each area at hapū or iwi level. Many of the Ngāi Tahu LPS described their hapū-based relationship with place, or involvement at iwi level, long-term local residents, and cultural-based environmentalist monitoring. The NZC LPS (non-Ngāi Tahu) described their relationship to place through intergenerational residency, involvement in farming and working the land, visiting and taking interest in management, and scientific ecological specialists who have monitored and researched these environments over time.

In addition, the traditional hapū relationship of Ngāi Tahu LPS was distinguished from the modern (post-claim) entity of iwi Rūnaka and Papatipu Rūnaka. Mana whenua is the hapū who whakapapa to each area, and these areas provide tūrangawaewae. As well the hapū hold customary rights to these areas. This right was legalised into the 1800 Ngāi Tahu ‘pink and blue’ whakapapa documents. Mana whenua of Te Akaaka (Rakahuri/Ashley-SC) is Ngāi Tūāhuriri. Both Ngāi Tūāhuriri and Ngāti Wheke have relationships with different boundaries of Te Ihutai Avon-Heathcote Estuary. Ngāti Wheke are the hapū and Mana whenua of Rāpaki Bay, Ngāti Huikai of Koukourārata and Pūrau Pā. Koukourārata area extends from Te Piaki (a.k.a Aderley Heads) to Pōhatu.

The estuary names used in this thesis were clarified within interviews. Using the name ‘Te Ihutai’ has its complications as this reserve was compulsory acquired under the Public Works Act (1928) in the 1950s and also impacted by the sewer/wastewater in the mid-20th Century, affecting both customary relationship and the fishery. A compensation block was designated in Rakahuri/Ashley-SC and named ‘Te Ihutai’. A further issue with this compensation was the widening of the highway impeding onto the recent Te Ihutai, thus reduced its size. There were multiple names given to the specific sites of Rakahuri Ashley Saltwater Creek Estuary, together they combined as Te Akaaka. Te Akaaka was also a specific name of one of the reserves. Port Levy was today called Koukourārata to local hapū and traditionally these were two pā, Pūrau (near marae, Pūrau road) and Koukourārata (where the rāhui and Pā road is located).

Traditional and cultural interaction and uses in each area according to LPS is as follows. People from the tribe Ngāi Tūāhuriri, especially located at Tuahiwi and Kaiapoi pā, would visit and stay at Te Akaaka for customary fishing purposes. A memory from the more recent past was spoken by a LPS, in his/her childhood when six to seven groups would be there collecting cockles and following the recreational limits. During that time there were no commercial fisheries. It was mentioned that the tribe still utilise this area, there are nohoanga sites (traditional seasonal occupation sites) for the iwi along Te Akaaka, and LPS are personally actively involved within working parties for the rivers and environment.

The Avon-Heathcote Estuary no longer supports a traditional cultural relationship as associated with mahinga kai, but are tribally associated and involved with other activities because of their whakapapa with the area. According to the LPS there were numerous pā and temporary kāinga (home/settlement) during pre-European times. Four LPS shared historical accounts and Waitangi Tribunal claim documents of Avon-Heathcote Estuary, and specifically Te Ihutai, which was a reserve set aside, was an important mahinga kai, fishery, and nohoanga area. Participants shared their knowledge of this place was learnt via intergenerational transfer of knowledge and documented accounts of mahinga kai along Ōtākaro (Avon River) and Ōpāwaho (Heathcote River). The mahinga kai sites extended from Ōtākaro to Ilam at the University of Canterbury, and Ōpāwaho to Ōpawa where kanakana (lamprey, *Geotria australis*) were documented in the 1950s. Mahinga kai, pelagic and benthic aquatic species, were impacted by the wastewater input. Upon the arrival of Europeans, it was said, that the estuary served for transportation, fishery, and today it is known to be highly valued by Christchurch residents and visitors.

Rāpaki and Koukourārata are important areas to Mana whenua and to all those who reside within the Bays. Both Ngāti Wheke and Ngāti Huikai also regard Te Whakaraupō, Lyttelton Harbour, as an important part of the moana to which they travel and gather from. A LPS referred to reading past documented descriptions of oyster abundance on Horomaka Island.

5.3.3. Activities

Gathering by Ngāi Tahu and Māori was done as whānau (family), i.e. with tamariki and mokopuna (children and grandchildren, respectively). In this whānau-centered activity whakapapa (genealogy) and kōrero o mua (traditional narrative) were shared with mokopuna, an organic transmission of transgenerational knowledge. Europeans and New Zealanders also enjoy these places with their family or as part of their leisure. New Zealand Europeans delighted in gathering food and relished the therapeutic nature of these natural environments.

Key activities (Table 5.1) included collecting/gathering fishery resources (29-100%), collecting/gathering inanimate resources (0-43%), leisure (50-67%), and other (0-50%). It is noted that there was fluidity between activities, for instance 'fishing' was also considered 'leisure' to some participants. Collecting/gathering fishery resources was done for consumption, leisure, and research/monitoring (including kaitiaki) purposes. The same proportion of Local Pracititioners and Specalists (LPS) and Recreational Practitioners (RP) gathered fishery resources at R-SC and AH, however, this significantly differed at Rāpaki and Koukourārata, where a higher proportion of LPS (100%) gathered compared to RP (38% and 76%, respectively; v^2 =89.41, DF=1.0, $p<0.0001$; v^2 =27.14, DF=1.0, $p<0.0001$).

Gathering fishery resources was further distinguished between those who fished, gathered shellfish, but excluded the plants due very low proportion (Table 5.1). Participants selected both fish and shellfish in some instances. The comparison of those who fished showed a higher proportion of LPS (86%) fished at Rakahuri/Ashley-SC than RP (50%), while no LPS fished or gathered at AH compared to RP (14%), which were significantly different (v^2 =29.63, DF=1.0, $p<0.0001$; v^2 =14.98, DF=1.0, $p<0.001$). The groups similarly fished at Rāpaki (29-40%) and Koukourārata (43-50%; $p>0.05$). Additionally, all LPS who fished, did so for consumption at all areas, except AH where they did not fish. Fishing for consumption was higher for LPS than RP at Rakahuri/Ashley-SC (86% and 45%, respectively) and Koukourārata (100% and 67%, respectively) which was significant (v^2=37.01, DF=1.0, $p<0.0001$; v^2=39.32, DF=1.0, $p<0.0001$). The same number of RP and LPS fished for consumption at Rāpaki (24% and 20%, respectively; $p>0.05$), and only RP (19%) did at Avon-Heathcote Estuary ($v^2=20.89$, $DF=1.0$, $p<0.0001$).

Comparing those who mentioned shellfish, a significantly higher proportion of LPS gathered shellfish compared to RP at all sites (R-SC $v^2=52.18$, $DF=1.0$, $p<0.0001$; Avon-Heathcote Estuary $v^2=10.55$, $DF=1.0$, $p<0.0001$; Rāpaki $v^2=132.67$, $DF=1.0$, $p<0.0001$; Koukourārata $v^2=79.32$, $DF=1.0$, $p<0.0001$). However, a lower proportion of LPS harvested at AH (40%) compared to other sites (71-100%), for research/monitoring compared to other sites. Additionally, no RP harvested from Rāpaki due to the rāhui in place, compared to other sites with active rāhui (Koukourārata – 43%), although were generally low at R-SC and AH (19-20%). Only LPS gathered within areas within the current rāhui, this was for monitoring and research, but RP did gather from outside of the rāhui. A significantly higher proportion of LPS than RP gathered shellfish at each area.

Shellfish consumption only occurred at R-SC by LPS (71%) and RP (20%; no table). Gathering by LPS at AH and Rāpaki was done for monitoring/research, and an LPS no longer gathered due to the earthquake. Some of the RP shellfish gatherers gathered at AH and Koukourārata for consumption (10% and 38%, respectively) and bait (10% and 10%, respectively). Many of the LPS shellfish gatherers did so for consumption (83%), and few did so for bait (17%) and research and monitoring (17%). Neither, LPS or RP collected shellfish for consumption at Rāpaki, due to the current rāhui. According to individuals of both groups, the rāhui had been extended due to food safety risks following the 2010 earthquake. As well, the rāhui was extended following an oil spill in Lyttelton Harbour in 2014. The rāhui remains in effect at the time of this research (Personal communication with the Ministry for Primary Industries Fishery Officer 2016). The consumption of bivalves between groups, was significantly higher for RP than LPS gatherers at Avon-Heathcote Estuary ($v^2=66.33$, $DF=1.0$, $p<0.0001$), and a higher number of LPS than RP at Koukourārata ($v^2=18.49$, $DF=1.0$, $p<0.0001$). Research and monitoring of bivalves was only done by LPS, and thus was significant at Avon-Heathcote Estuary and Rāpaki (both $v^2=49.75$, $DF=1.0$, $p<0.0001$) and Koukourārata ($v^2=18.49$, $DF=1.0$, $p<0.0001$).

Table 5.1. The activity of the Local Practitioners and Specialists (LPS) and Recreational Participants (RP) at each estuarine study area: Rakahuri/Ashley-Saltwater Creek Estuary (R-SC), Avon-Heathcote Estuary (AH), Rāpaki Bay (R), and Koukourārata/Port Levy (K). Activities were divided into fishery resources inanimate resources (e.g. stones, shells), leisure (e.g. boating, kayaking, waka ama), and other.

Activity (number of participants/total participants interviewed)

Area	**Group**	Fishery resources			Inanimate resources	Leisure	Other
		Total	Fish	Shellfish			
R-SC	LPS (n=7)	86%	86%	71%	43%	57%	43%
	RP (n=20)	75%	50%	20%	15%	20%	20%
AH	LPS (n=5)	40%	0%	40%	40%	60%	40%
	RP (n=21)	29%	14%	19%	0%	67%	19%
R	LPS (n=5)	100%	40%	80%	20%	60%	40%
	RP (n=21)	38%	29%	0%	5%	67%	0%
K	LPS (n=6)	100%	50%	100%	33%	50%	50%
	RP (n=21)	76%	43%	43%	10%	67%	10%

Both LPS (34.78%) and very few RP (7.23%) collected inanimate resources (Table 5.4). Most of these LPS participants (87.5%) were affiliated to Ngāi Tahu and collected large greywacke for cooking food (hāngi –earth oven), mud to dye flax, animal bones to create kōauau (flute) and stones/shells as ornaments. One participant (12.5%) who affiliated as European collected shells during research. Rubbish was also collected to maintain beach/shore. Recreational Participants collected shells, stones, feathers, and sea china. The NZC (66.67%) and visitor (16.67%) participants gathered inanimate resources for ornamental purposes. Ngāi Tahu RP (16.67%) amassed shells for their home garden and as ornaments. The collection of inanimate resources was significantly higher by LPS than RP at Rakahuri/Ashley-SC (v^2 =18.94, DF=1.0, $p<0.0001$), Avon-Heathcote Estuary (v^2=49.75, DF=1.0, $p<0.0001$), Rāpaki (v^2 =10.23, DF=1.0, $p<0.005$), and Koukourārata (v^2=15.59, DF=1.0, $p<0.0001$).

Whakapapa and kōrero o mua (traditional narrative/story) of these environments were shared during the interviews. The estuarine environment is personified within a Māori worldview. For example, replanting of the native riparian stream was to connect 'te pito ki te moana' (literally '*from the point/centre/navel to the ocean/coast*'), thus connecting earth to sea. Not only was whakapapa referenced to their tūrangawaewae – the 'place where one stands' (genealogically), this also included the ecosystem's animate and inanimate objects. Whakapapa and mauri are imbued within landscape features as illustrated in assembling estuary, stones, and the core components of the hāngi. Whakapapa ensures a cycling relationship between the environment and people. Mauri was indicated by the activity and presence of animal life (avian, fish, shellfish). Mud was used to dye flax, flax was used to weave baskets and to tie fish together.

Partaking in leisure activities included several on-water activities (waka ama, kayaking), land and beach-based (walking, sitting) activities at each area (Figure 5.4). Walking, including walking with their dog, as well as swimming were the most popular leisurely activities at each area. An exception was at Avon-Heathcote Estuary where direct contact only related to fishery activity or research. Sitting and eating were only mentioned at Rakahuri/Ashley-SC and Rāpaki, while motorised boating and water skiing were only based at Koukourārata.

The proportion of either RP or LP that participated in leisure activities was similar at Avon-Heathcote and Rāpaki (60.0% LPS, 67.0% RP), was a little higher for RP (67%) than LPS (50.0%) at Koukourārata, and less so for RP (20.0%) than LPS (57.1%) at Rakahuri/Ashley-SC. However, the latter difference did this not include the swimming zone further down the beach at Waikuku, further south from Rakahuri/Ashley-SC. The participation in leisurely activity was significantly different between participant groups at Rakahuri/Ashley-SC (v^2=28.79, DF=1.0, p<0.0001) and Koukourārata (v^2=5.92, DF=1.0, p<0.005).

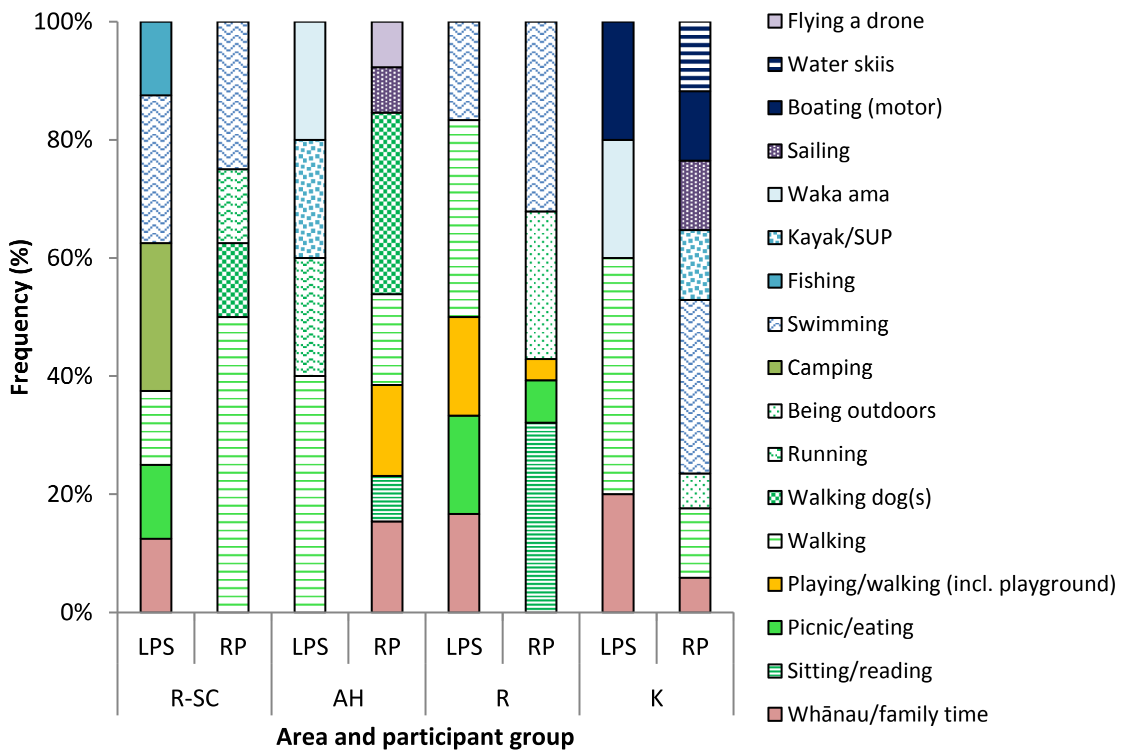


Figure 5.4. The frequency (%) of leisure activity by Local Practitioners and Specialists (LPS) and Recreational Participants (RP) at the four Canterbury estuarine areas (N=106).

The Local Practitioners and and Specialists (LPS) were involved in other activities at a much higher proportion (47.82%) than Recreational Participants (RP; 13.25%). Other activities included bird and wildlife watching (7.23%) by RP at Rakahuri/Ashley-SC and Koukourārata. Activities done only by LPS included replanting (4.35%) and marine farming (4.35%) at Koukourārata, cultural environmental index monitoring and ecological research by LPS (26.09%), mahi as tangata tiaki (13.04%), ranger (4.35%), and discussing whakapapa (8.70%). ‘Other activities’ were significantly higher for LPS than RP at Rakahuri/Ashley-SC (v^2=7.18, DF=1.0, p<0.01), Avon-Heathcote Estuary (v^2=10.55, DF=1.0, p<0.005), Rāpaki (v^2=49.75, DF=1.0, p<0.0001), and Koukourārata (v^2 =68.27, DF=1.0, p<0.00001).

The best times for people’s main activities in each estuary varied between participant groups (Table 5.2). Less RPs provided information for this section, and both the LPS and RP selected multiple criteria each, therefore the results are represented by fraction rather than percentage. The LPS who fished or gathered for consumption or research purposes, was done throughout the year (5/23) unless it was season-specific (5/23), and those who harvested did not do so in winter (6/23, Table 5.2A). Many of the RP fishers favoured the summer (16/83) and throughout the year (12/83), and less did so seasonally (4/83) or winter (5/83). In terms of leisure and gathering of inanimate resources (Table 5.2B), some of the same periods were referred by RP (all year 7/83, seasonally 5/83, and summer 23/83). The majority of the LPS did not answer this section (22/23), because gathering was part of their leisurely interaction with place or they did not favour leisure-specifically (Table 5.3).

Multiple sites were utilised for fishery and research of fishery purposes (Table 5.3A). Fishery and/or research were done by LPS across multiple sections of the area/bay (7/23), inner estuary (6/23), beach (4/23), and were tide-dependent (9/23). Fishing by RP utilised the pier/wall (13/83), estuary (9/83), river/river bank (6/83), beach (6/83), and tidal zones (11/83). In terms of leisure (Table 5.3B), the majority of the LPS did not answer the sites for leisure section as per the above paragraph. The areas for LPS leisure were the estuary (1/23), river/river bank (1/23), and tidal-dependent (1/23). The RP favoured the beach (15/83), pier (9/83), and estuary (6/83), and fewer mentioned boat/on-water (2/83), river/riverbank (1/83), playground (2/83), and marae (2/83).

Table 5.2. The best times for site activities and frequency mentioned by Local Practitioners and Specialists (LPS) and Recreational Participants (RP). Site activities included: (A) gathering/fishing for animate (e.g. shellfish) and inanimate (e.g. shells) resources for eating/bait/monitoring/research, and (B) leisure activities (e.g. boating, kayaking, waka ama) (N=106).

Best times:	All year/anytime	Seasonal	Summer	Winter	Not winter	Months without R	Moon	n/a
A. Gathering/fishing/monitoring activities								
LPS	5/23	5/23	3/23	2/23	6/23	1/23	1/23	0
RP	12/37	4/37	16/37	0	5/37	0	0	0
B. Leisure activities								
LPS	1/23	0	0	0	0	0	0	1/23
RP	7/37	5/37	23/37	0	1/37	0	0	1/37

Table 5.3. The best areas for site activities and frequency mentioned by Local Practitioners and Specialists (LPS) and Recreational Participants (RP). Site activities included: (A) gathering/fishing for animate (e.g. shellfish) and inanimate (e.g. shells) resources for eating/bait/monitoring/research, and (B) leisure activities (e.g. boating, kayaking, waka ama) (N=106).

Areas:	All the bay/area	Estuary	Rocky shore	Boat/ in water/ aqua-farm	River/ river bank	Jetty/ Pier/ wall	Beach/ sea side	Land: forest, grass area	Playground	Place: marae, yacht area	Tidal
A. Gathering/fishing/monitoring activities											
LPS	7/23	6/23	2/23	1/23	2/23	2/23	4/23	0	0	0	9/23
RP	3/83	9/83	5/83	4/83	6/83	13/83	6/83	0	0	0	11/83
B. Leisure activities											
LPS	0	1/23	0	0	1/23	0	0	0	0	0	1/23
RP	3/83	6/83	0	2/83	1/83	9/83	15/83	3/83	2/83	2/83	3/83

5.3.4. Favoured and targeted fishery resources

Favoured and targeted resources included shellfishes, fishes, and plant life at each respective area (Figure 5.5-5.6). Both the full scientific and Māori names of these species are provided in Table 5.4. Bivalve species were mentioned by both participant groups at each site, especially cockles/tuangi (7-27%), and saltwater clams/pipi (3-27%), with exception of RP at Rāpaki. Saltwater mussels/kūtai were mentioned at only two areas, Rāpaki (7%) and Koukourārata (13-28%), and true oysters/tio (3-13%) only at the latter site. Both the Local Practitioners and Specialists (LPS) and the Recreational Practitioners (RP) enjoyed surveying and observing manu/bird life (9-40%) at Rakahuri/Ashley-SC, Avon-Heathcote Estuary and Rāpaki. Fish in general was mostly mentioned by RP at Rāpaki and Koukourārata. Inanga/whitebait (galaxiids, 16-21%) and tuna (freshwater eel, 3-16%) were only mentioned at Rakahuri/Ashley-SC, and favoured by both participant groups.

Certain species, such as tuangi, were not gathered at certain areas at the time of participant interviews as indicated within the site activities (Section 5.3.3). However, these were important resources for participants (Figure 5.5-5.6) who would prefer to be able to gather these (R and K LPS, R-SC and AH RP). The most common shellfish and fishery groups amongst areas were the clam and cockle (tuangi), saltwater clams (pipi/taiwhatiwhati), and righteye flounders (pātiki, Figure 5.5 and 5.6). The inanga was also commonly mentioned as a target species, but unique to R-SC (Figure 5.5), though participants had observed whitebaiters within the Avon River. Two rocky shore shellfish kūtai and tio, were also unique to Rāpaki and Koukourārata, however tio were only mentioned to be available in the past at Rāpaki (Figure 5.4). The frequency of participants who favoured bivalve species suggested that tuangi was mentioned more by LPS than RP at Rakahuri/Ashley-SC ($v^2=6.15$, DF=1.0, $p<0.05$), Rāpaki ($v^2=10.18$, DF=1.0, $p<0.01$), and Koukourārata ($v^2=9.87$, DF=1.0, $p<0.01$). A higher number of LPS than RP favoured saltwater clams (pipi/taiwhatiwhati) at Rāpaki ($v^2=8.92$, DF=1.0, $p<0.005$), and tio/oysters at Koukourārata ($v^2=8.05$, DF=1.0, $p<0.005$). Kūtai was mentioned just as often by LPS and RP, so they were not statistically different between groups ($p>0.05$).

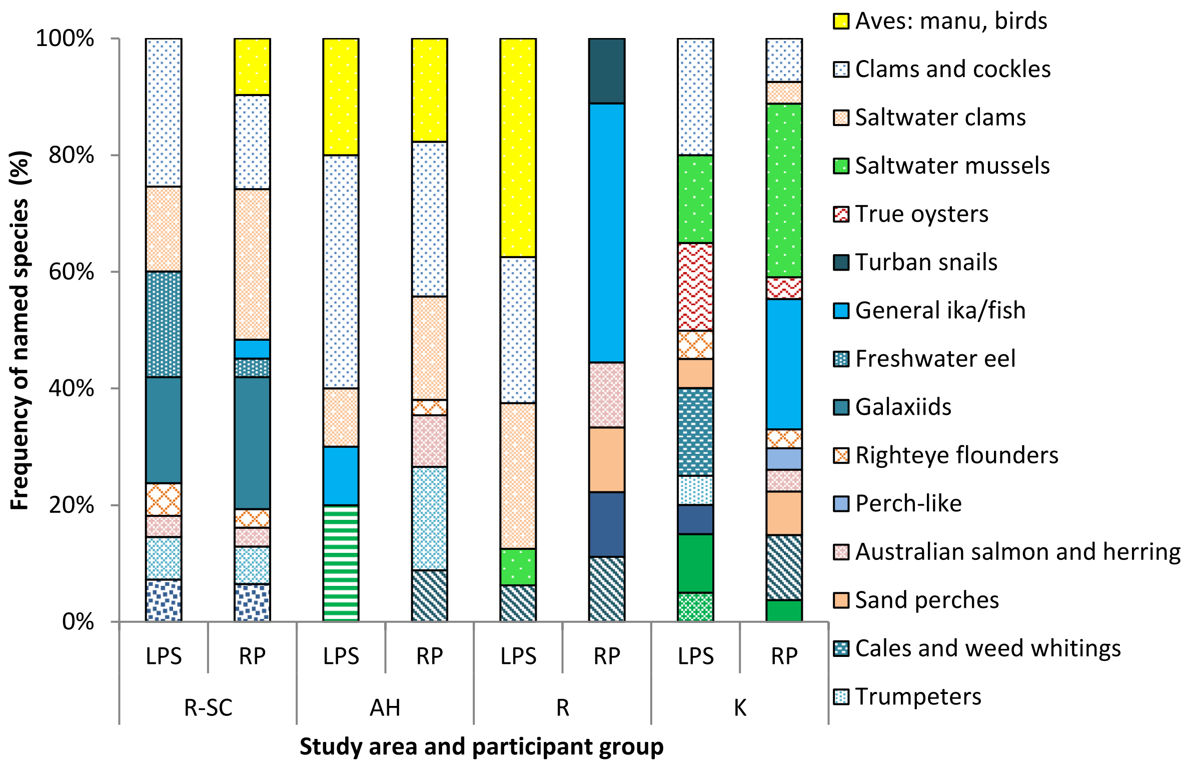


Figure 5.5. Frequency (%) of favoured estuarine species named by Local Practitioners and Specialists (LPS) and Recreational Participants (RP). These are grouped by scientific class, except where general terminology was given (i.e. ika/fish) N=106. See Table 5.5 for the full classification., and Table 5.1 for area names.

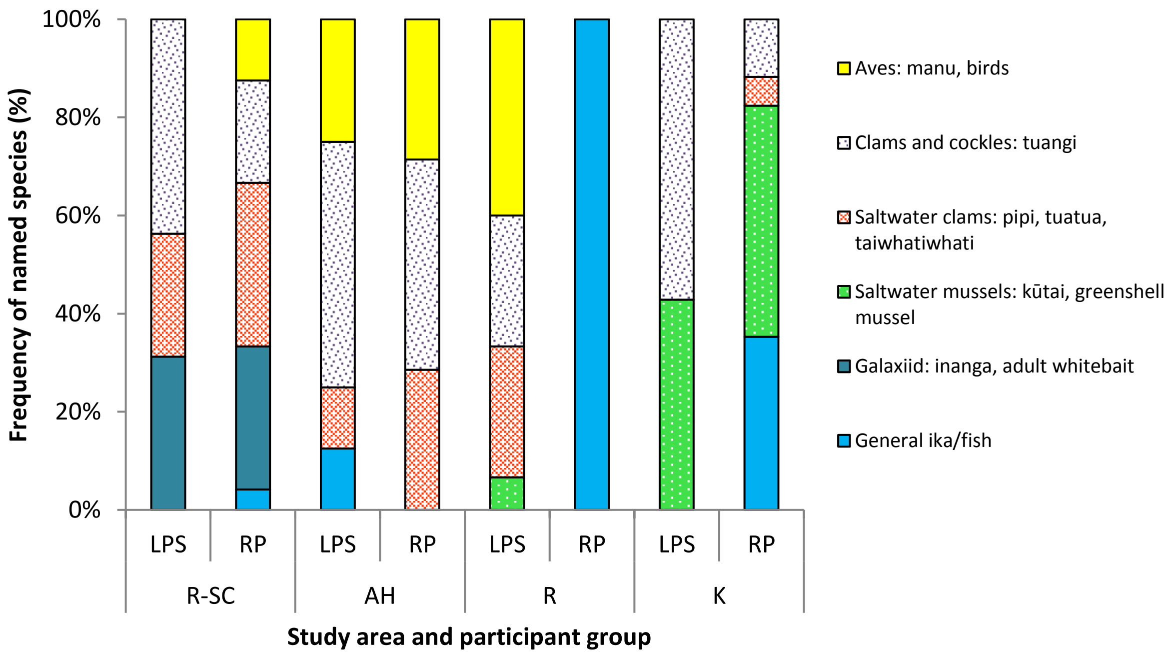


Figure 5.6. Frequency (%) of favoured bivalves and fisheries species named by Local Practitioners and Specialists (LPS) and Recreational Participants (RP).. These are grouped by scientific class and common names (N=106). Table 5.5 for the full classification, and Table 5.1 for the area names.

Table 5.4 The scientific, Māori (general and Ngāi Tahu iwi), and common names of favoured fish and shellfish species.

Family	**Common family**	**Māori name**	**General name**	***Genus***	***Species***
Veneridae	Clams and cockles	Tuaki/Tuangi	New Zealand cockle	*Austrovenus*	*stutchburyi*
Mesodesmatidae	Saltwater clams	Pipi/Taiwhatiwhati	Pipi	*Paphies*	*australis*
Mytilidae	Saltwater mussels	Kūtai	New Zealand green-lipped mussel	*Perna*	*canaliculus*
		Kūtai	Blue mussels	*Mytilus*	*edulis*
Ostreidae	True oysters	Tio	Oysters	*Tiostrea*	*chilensis*
Haliotididae	Pāua and abalone species	Pāua	Blackfoot Pāua	*Haliotis*	*iris*
Turbinidae	Turban snails	Pupu	Cat's eye snail	*Lunella*	*smaragdus*
Echinometridae	Sea urchins	Kina	Sea urchin	*Evechinus*	*chloroticus*
Portunidae	Swimming crabs	Pāpāka	Paddle crab	*Ovalipes*	*catharus*
Anguillidae	Freshwater eel	Tuna	Short and long-finned eel	*Anguilla*	*spp.*
Galaxiidae	Galaxiids	Inanga (adult)	Whitebait, common Galaxias	*Galaxias*	*maculatus*
Retropinnidae	Bony fishes include Southern Hemisphere smelts and graylings		Common smelt	*Restropinna*	*retropinna*
Pleuronectidae	Righteye flounders	Pātiki	Sand flounder	*Rhombosolea*	*plebeia*
Arripidae	Australian salmon and herring	Kahawai	Kahawai, Eastern Australian Salmon	*Arripis*	*trutta*
Pinguipedidae	Sand perches	Rawaru, Pakirikiri	New Zealand blue cod	*Parapercis*	*colias*
Odacidae	Cales and weed whitings		Green-boned butterfish	*Odax*	*pullus*
Latridae	Trumpeters	Moki	Blue moki	*Latridopsis*	*ciliaris*
Mugilidae	Mullets	Kanae (South Island)	Herring, yelloweye mullet	*Aldrichetta*	*forsteri*
Salmonidae	Salmon and allies		Brown trout	*Salmo*	*trutta*
	Salmon and allies		Pacific salmon, chinook salmon	*Oncorhynchus*	*tsawytscha*
Zeidae	True dories		John dory	*Zeus*	*faber*
Triakidae	Houndsharks		Rig, lemmonfish, spotted estuary smooth-hound	*Mustelus*	*lenticulatus*
	Houndsharks		School shark, tope shark	*Galeorhinus*	*galeus*
Callorhinchidae	Plough-nose chimaeras		Elephant fish	*Callorhinchus*	*milii*

Fishery changes over time

The majority of Local Practitioners and Specialists (LPS) at Rakahuri/Ashley-SC (85.71%), Rāpaki (100%), many LPS at Koukourārata (69.57%), and only one LPS at Avon-Heathcote Estuary (20%), agreed that the favoured resources changed over time. At Rakahuri/Ashley-SC (40%), Avon-Heathcote Estuary (14.29%), Rāpaki (4.76%), and Koukourārata (20%), fewer Recreational Practitioner (RP) concurred with the previous view of favoured resources changing over time. Participants with less than five years experience did not provide answers for this question.

The reported mean relative abundance of tuangi and saltwater clams (pipi/taiwhatiwhati) at Rakahuri/Ashley-SC was similar between participant groups (Figure 5.7). The perceived tuangi abundance by LPS and RP was 58%±0.20 and 69%±0.19, and saltwater clams was 70%±0.30 and 69%±0.19, respectively. The perceived abundance of inanga and pātiki differed between groups, the LPS perceived abundance at 40%±0.12 and 28%±0.06, respectively, and RP 63%±0.16 and 75%±0.25 respectively. The perceived abundances at Rakahuri/Ashley-SC was not statistically significant between participant groups or experience.

Abundances were not compared for the Avon-Heathcote as only two RP reported declined changes, and a LPS perceived increased abundance. Only LPS provided relative abundance information at Rāpaki. The LPS reported an abundance of 46%±0.20 of tuangi and 92%±0.08 of pipi remain (Figure 5.7). These data could not be statistically analysed due to low sample sizes.

In contrast to Rakahuri/Ashley-SC, the Koukourārata LPS reported higher relative abundances than RP, however not many RP reported (n=2). According to LPS, tuangi abundance was 88%±0.13, kūtai 100%±0.00, and pātiki was 53%±0.32 (Figure 5.7). In comparison, RP did not report on tuangi abundance, however, they perceived kūtai abundance is 50%±0.00, and pātiki was 50% (no S.E.). The perceived abundances were not statistically significant between participant groups or experience.

Certain species, included tuangi, were regarded by a small number of people to have declined or were no longer available at the following three areas: Rakahuri/Ashley-SC (1/27), Rāpaki (2/26), and Koukourārata (1/27, Table 5.5). The correlation analysis showed no significant relationship between perceived species abundance with participant experience.

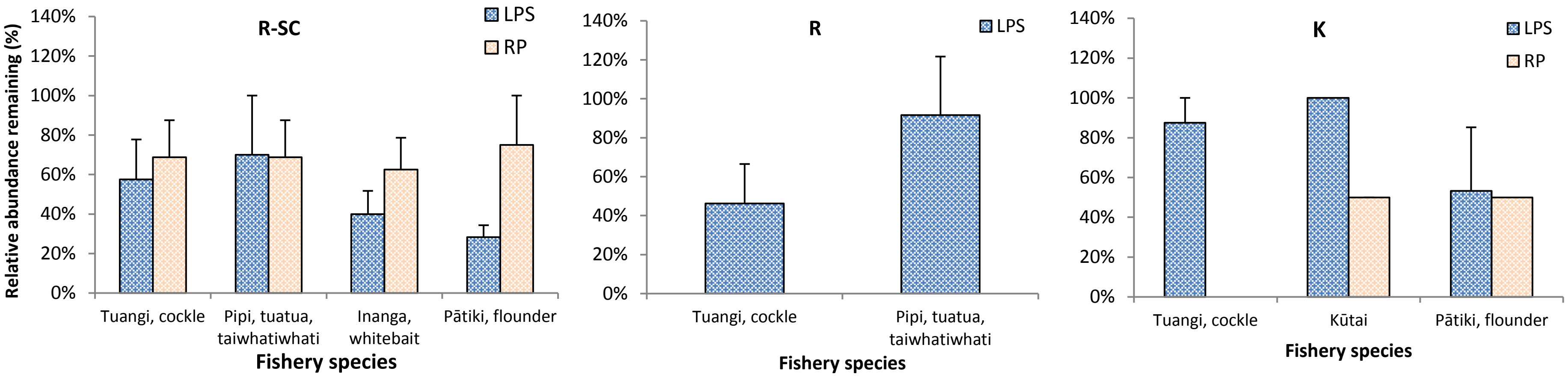


Figure 5.7. The relative abundance (%) of commonly named species. The Recreational Participants (RP) abundance results from the Avon-Heathcote (AH) (N=2) and Rāpaki were omitted, and there were no Local Practitioners and Specialists (LPS) results at AH.

Table 5.5. Fishery species perceived to have declined or are no longer available in three Canterbury estuaries.

Organisms	Rakahuri/Ashley-Saltwater Creek	Avon-Heathcote Estuary	Rāpaki	Koukourārata
Tuangi, cockles	1* (at Saltwater Creek)		2	1
Pipi			1	
Kūtai, mussels				1
Tio, oysters				2
Paddle crab			1	
Kekewai/Wai kōura/freshwater crayfish	1			
Kōura, crayfish				1
Shrimp	1	1		
Inanga, whitebait		1		
Tuere, hagfish	1			
Kanakana, lamprey	3			
Pātiki, flounder				1
Rawaru, cod				2
Butterfish				1
Grouper				1
Kaiau, sea tulips				1
Sea horses				1
Fish (general)			2	
Turnstone waders	1			

5.3.5. Environmental condition, indices, and changes

Environmental condition

Participant group

A large proportion of Recreational Practitioners (RP; 50-90%) perceived the condition at the site of activity as good-excellent at each estuary (Figure 5.8). Few RP scored the catchment. The catchment was scored poor-fair (55%) at Avon-Heathcote Estuary, good-excellent (45%) at Rakahuri/Ashley-SC, and over half (57%) from Koukourārata rated the catchment good-excellent. Some did not answer at the latter two sites (45% and 29%, respectively). The Local Practitioners and Specialists (LPS) generally scored the site and catchment at a lower environmental condition score than the RP (Figure 5.8). The LPS at Rakahuri/Ashley-SC equally rated the site and catchment as poor-fair (57%) and good-excellent (43%). Participants from the Avon-Heathcote Estuary rated both site and catchment poor-fair (80% and 60%, respectively) and less as good-excellent (20%), and some did not score the catchment (20%). The Rāpaki site and catchment were scored poor-fair (60%) and less as good-excellent (40%). Koukourārata site and catchment were evenly distributed between both ratings (50%). The environmental scores by participant groups were scored higher by RP than LPS for the site and catchment at each estuary ($p<0.05$, Table 5.6).

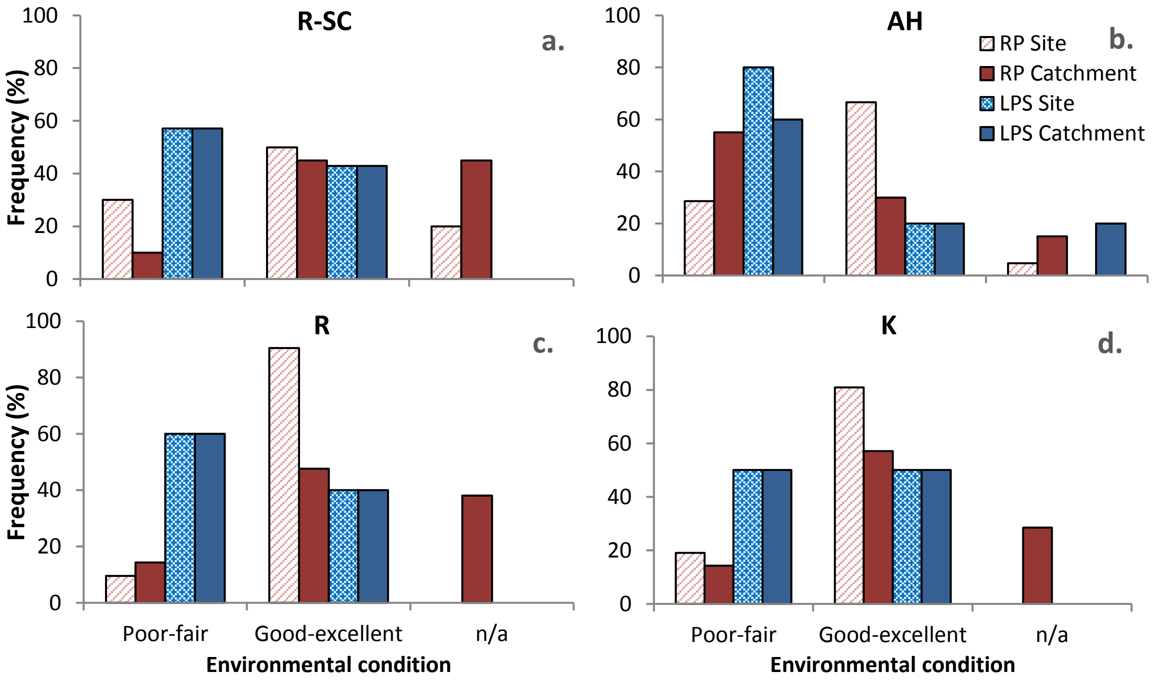


Figure 5.8. The percent frequency of environment condition (poor to excellent) at each area according to Local Practitioners and Specialists (LPS) and Recreational Participants (RP) (N=106).

Table 5.6. Fisher analysis results of perceived environmental scale (poor-fair and good-excellent) for each area between participant groups – Local Practitioners and Specialists (LPS) and Recreational Participants (RP) (N=106). Significant values in bold. Area names are provided in Table 5.1.

Area and scale	Group (LPS and RP)	
	v²	p-value
R-SC Site	6.73	**<0.05**
R-SC Catchment	21.65	**<0.0001**
AH Site	48.94	**<0.0001**
AH Catchment	4.82	**<0.05**
Rāpaki Site	54.67	**<0.0001**
Rāpaki Catchment	21.46	**<0.0001**
K Site	21.16	**<0.0001**
K Catchment	16.16	**<0.001**

The qualitative descriptions accompanying the above site scores are as follows (Table 5.7). The poor-fair scores rated by RP related to sediment conditions (e.g., silt, scoured), decline in shellfish/fishery abundance and fish condition, poor water quality (unsafe for swimming), and damaged structures (jetty/wharf due to earthquake). Sites considered poor-fair by LPS were related to the perceived changes over time, particularly to waterway conditions, water quality (unsafe to gather food), and shellfish condition (e.g., oysters were fair). The RP related good-excellent scores were represented by an abundance of large sizes of fish and shellfish, supports bird life, site amenities and aesthetics (walkway, clean/tidy). The LPS reported good-excellent scores were based temporal comparisons, the natural condition, fish condition, and site knowledge. The scores were not necessarily inclusive of the entire estuary, because both participant groups perceived intra-site variability. For example, fishing was safer close to the mouth of the estuary due to contaminants further up (AH RP). A certain sectors had become silted up altering waterway volume (R-SC LPS, Table 5.7).

Examples of the catchment qualitative descriptions are as follows (Table 5.8). Catchment scored poor-fair by RP related surrounding land-use or industry, sediment condition, polluted waterways, water quality (impact swimming and fishing), and earthquake impacts. The poor-fair scores rated by LPS also related to land uses and industry and vegetation, increased cyanobacteria, waterway and sediment condition (tidal depression), increased catch-per-united-effort, pollution. The good-excellent rated catchments by RP related to native vegetation and land uses (replanted riparian zones, native forest, and little grazing). The LPS related their good-excellent scores to reducing contaminants input (metals and no sewage), increased vegetation, and less housing developments. Some of the descriptions that were associated with good-excellent catchment scores by RP and one LPS referred to the site level (Table 5.8). This score given by RP related to good beach access, safe shellfish health and low microbiological levels (e.g., *E. coli*), fishery regulation, beach vehicle restrictions, and recreational wellbeing (great place to be, leisure, improved playground, dog walking area). The LPS related their high scores to large fishery spawning grounds. There were examples of mismatched scores with comments. Although participants scored a site good-excellent, their comment was the site sometimes smells (RP), and post-earthquake restoration was required (LPS). Similarly, at the catchment level, a good-excellent score was associated with comments of rubbish as a problem (RP), the maunga (mountain) was impacted by earthquake (LPS), and there is dredging, with muddy runoff during winter (RP).

Table 5.7. Qualitative site score descriptions provided by Local Practitioners and Specialists (LPS) and Recreational Participants (RP)and grouped by the area. Key words and phrases are in bold. Area names are provided in Table 5.1.

Poor-Fair
Poor for the **whole estuary area. I think each tributary has its own impact** on the **whole estuary area** (R-SC LPS). **It is silty** (RP). **Shellfish beds have become smaller** and smaller (RP). Fishing is poor-fair (RP).
Wouldn't swim (AH RP). **The fish quality is not good** as elsewhere (RP). Wouldn't **fish** here (RP). Fair for cycling, but **worse during rain and runoff** (RP). There is room for improvement, commented on the Bromley treatment plant and the mussel farms in Pegasus Bay **changing the ecology of the estuary** (RP). Clear and pleasant (RP).
Food gathering has diminished and it is polluted. We are not allowed to gather because it is **not safe** (R LPS). The bay is **empty of fish** (RP).
Compared to the past it is poor (K LPS). The oysters are fair (LPS). Water condition ok, **jetty is fenced off** (RP). It has **scoured out** quickly all around the bay (RP). **Have never seen the water clear**, it is either sediment or algae or turbidity, I'm not sure. Slimy bottom when swimming, winter is more clear (RP). Wharf **needs repairs** (RP).
Good – Excellent
Nothing much has changed except a certain area has become **silted up, and there is far less water in the river**. That is one of the main causes when the **fish migrate up they have nowhere** to go (R-SC LPS). The **bird life has picked** up a lot more in 25 years, the dotterel, oystercatchers, and terns are looking good (LPS). The Ashley [fishery] is more abundant (RP). **Pipi** [beds are] **thicker at this site** (RP). There are more numerous shellfish at home (North Island), but there are **bigger sizes here** (RP). It's variable, **mud in areas, sandy to gravel other areas**. **Sand dunes built up** at Waikuku now (RP).
They were **testing for contaminants, [it's] good close to mouth** (AH RP). **No difference [over time], the earthquake didn't help**, 15 years here (RP). Clear and pleasant (RP). **Excellent for birds** (RP). Water and walkway (RP). Generally tidy (RP). All the equipment safe (RP).
Earthquake changed **some parts lots of work to do, but it will get there** (R LPS**)**. **Sometimes smelly** (RP). **It's beautiful - feels clean** (RP); It is average (score =3) I **know where to go** (K LPS). **Natural** – it hasn't been compromised, **the fin fish are in between good and excellent** (LPS). Depends where in the bay you are it varies, **rocks this end is silty,** there is **sandy area,** lots of seaweed on rocks, **various species shellfish** around by Pā road (RP). Good for **swimming** (RP).

Table 5.8. Qualitative catchment score descriptions provided by Local Practitioners and Specialists (LPS) and Recreational Participants (RP)and grouped by the area. Key words and phrases are in bold. Area names are provided in Table 5.1.

Poor-Fair
Long-term **adjacent land use, I'm conscious of industrial use** (R-SC LPS). **Progress** [land uses] is not healthy, **affecting site**, need a rubbish bin (RP). A bit worrying with the **high nitrates from farming**. It wasn't pristine, but 25-30 years ago, it seemed to have **better health in the Ashley main river, and Saltwater Creek had reasonable fish**, but water quality didn't seem the best. Over the last 11-12 years there is **cyanobacteria** in Ashley, the **flow drops off then the algae grow** (LPS). **Dairy runoff** further up**, this river had a shingle bottom and freshwater, has changed to mud over last 10 years** (RP). **It was tidal, now it's a huge tide with a depression and higher [salt] water input.** The level of the river bed has come up **with silt and shingle**. When my grandfather was young, the main road of Ashley bridge **had sand**, and they trawled for flounder there (LPS).
The **closer to river input is more polluted** (Fair), so **gradient of condition**, water conditions are good here [near the mouth] (AH RP). **This side [Avon] is clean**, **the other side [Heathcote] is dirty** (RP). The general **waterway health** is poor (LPS). **I wouldn't swim here** (RP). The **city** impinged **on the mudflats** (RP). The **runoff** is bad (RP). Improved until **earthquake**, there was more flounder and herring than before. **Now reluctant to catch fish** (RP). **Post-earthquake** road works (2xRP), **EQ** affected **access and shingle input** (RP). The bay is **impacted by the Port** (R LPS).
The storm in April wiped out fencing and the **replanted areas**, we need to do **whole catchment Ki Uta Ki Tai - whole circle in Te Ao Māori** (K LPS). Problem is that **lower silty stuff washes in with rain and increases turbidity**, and could seep out of **septic sewage systems** (K). The **earthquake** really hit here (LPS). The **kaimoana has declined, there is a higher CPUE**, and **pollution** (LPS).
Good-Excellent
Lots of habitat - **old Taranaki, lagoon, and south bank are big [whitebait] spawning grounds** (R-SC LPS). **Still healthy and kai there** (LPS). Called Council about the **rubbish dumping** (RP). **Beach access** (RP). Whitebaiters regulated, less driving on beach (RP). The **Ashley catchment is extensive** (RP). **Wonderful** (RP).
Wider catchment has influenced the estuary, today there is **less contaminant and no treated sewage** entering the estuary, there are **still things from the river** so the **water quality** in the estuary **is not suitable for swimming,** but it is probably better than what it was. (AH LPS). **Whitebait** goes up estuary (RP). **Playground area improved, good dog walking** site (RP). **Beautiful** (RP), Love it (RP).
Maunga has been **hurt by earthquake, [housing] developments** (R LPS). Wider catchment has changed over 20 years, lots more vegetation (LPS). Include the mountains (RP). **Beautiful site** (RP). Good for **leisure activity** (RP).
Good ground cover, **no bush** since 1000 years ago (K LPS). Good, **except winter, rains, muddy runoff from the hills, and dredging** in Lyttelton (RP). Stream here has **native plants**; **little grazing upstream has native forest**. **Shellfish health** - ***E. coli* were fantastic** (RP). **Replanting up two streams** (RP). Would love to live out here (RP). Great place to come being out here (RP).

Participant experience

The perceived environmental condition was rated higher by those participants with less experience (<20 years, Figure 5.9). Many of these participants (<20 years) rated sites good-excellent at Rakahuri/Ashley-SC (63%), Avon-Heathcote Estuary (73%), Rāpaki (65%), and Koukourārata (79%). Some of the participants ranked sites poor-fair or did not answer at Rakahuri/Ashley-SC (19% and 19%), Avon-Heathcote Estuary (20% and 7%), Rāpaki (18% and 18%), and Koukourārata (16% and 5%). Many more experienced participants (20-30 years) rated sites poor-fair at Avon-Heathcote Estuary (64%), and Rāpaki (63%), and half of the proportion at Rakahuri/Ashley-SC (55%) and Koukourārata (50%). The remaining proportion ranked sites as good-excellent (38-50%).

Many of the less experienced participants ranked the catchment good-excellent except at the Avon-Heathcote Estuary (Figure 5.9). The proportion of poor-fair and good-excellent were Rakahuri/Ashley-SC (6%, 50%), Avon-Heathcote Estuary (47% and 40%), Rāpaki (12% and 47%), and Koukourārata (5% and 63%) respectively. The remaining proportion did not answer (13-44%). A higher proportion of more experienced participants voted poor-fair compared with good-excellent at Avon-Heathcote Estuary (64% and 18%) and Koukourārata (63% and 38%). The score was evenly distributed at Rakahuri/Ashley-SC (45% and 45%), and half of the participants ranked higher values at Rāpaki (38% and 50%). Those with less experienced scored the site and catchment significantly higher than more experience participants (Table 5.9).

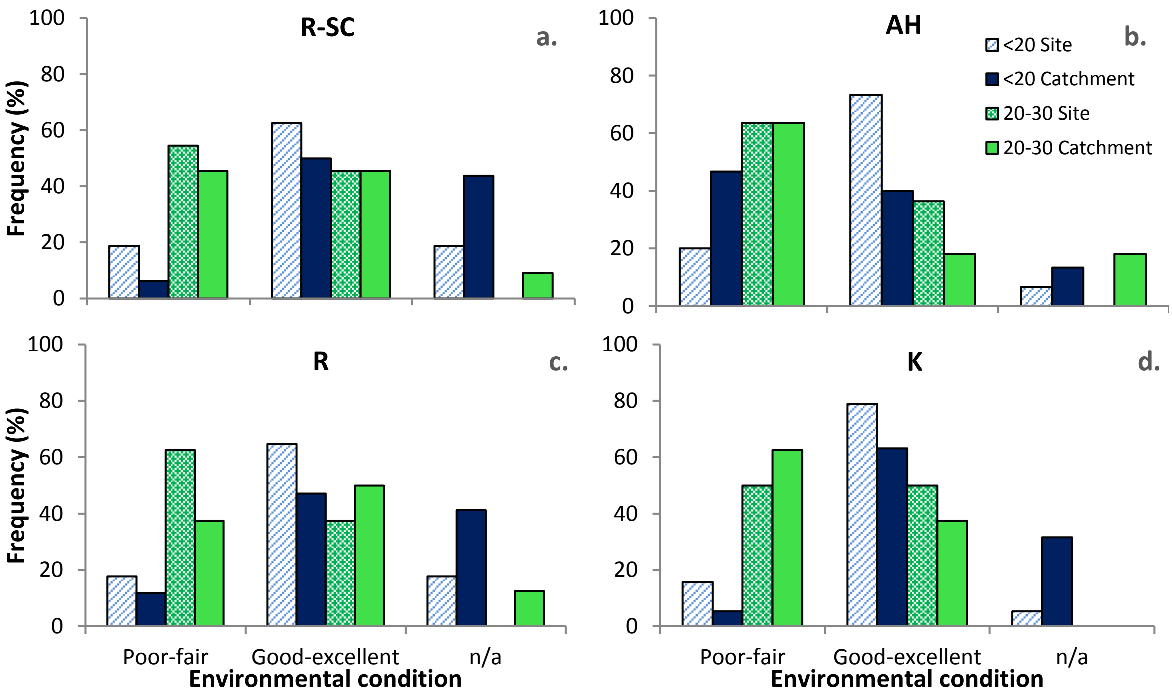


Figure 5.9. The perecent frequency of environment condition (poor-fair to good-excellent) at each area according to participants with less experience (<20) or more experience (20-30 years) (N=106). Area names are provided in Table 5.1.

Table 5.9. Fisher analysis results of perceived environmental scale (poor-fair and good-excellent) for each area between participant experience. Significant values in bold. Area names are provided in Table 5.1.

Area and scale	**Experience**	
	<20 and 20-30	
	v^2	p-value
R-SC		
Site	18.81	**<0.0001**
Catchment	23.28	**<0.0001**
AH		
Site	4.82	**<0.05**
Catchment	18.24	**<0.0001**
R		
Site	30.44	**<0.0001**
Catchment	8.16	**<0.0001**
K		
Site	23.92	**<0.0001**
Catchment	50.86	**<0.0001**

Cultural affiliation

The environmental condition was also a function of cultural affiliation. At Rakahuri/Ashley-SC the poof-fair site and catchment scores (64% and 83%, respectively) were primarily Ngāi Tahu, compared to the good-excellent scores given by people who affiliated as New Zealand born citizens and permanent residents who were not Māori (i.e. New Zealand European/ 'kiwi'), herein named 'NZC' (62% and 69%, Figure 5.10 a-b). The perceptions of NZ Māori (who did not affiliate to Ngāi Tahu) participants differed from Ngāi Tahu iwi. A higher proportion of NZ Māori than non-Māori ranked site and catchment good-excellent (15% and 8%) than poor-fair (9% and 0%) respectively.

All Ngāi Tahu participants at Avon-Heathcote Estuary perceived the site poor-fair, making up 27% of the score, the remaining 73% were affiliated to NZC (Figure 5.10 c-d). Most participants who perceived the site good-excellent were also NZC (86%) as well as NZ Māori and visitors (7% and 7%). The catchment scale ranking was similar with the proportion of poor-excellent were Ngāi Tahu (14%) and NZC (86%). The good-excellent catchment scores were associated to NZC (75%) and NZ Māori and visitors (13% and 13%).

The proportion of ranked scores at Rāpaki site and catchment were similar to the previous study area (Figure 5.8 e-f). Those who respectively ranked the site and catchment good-excellent were mostly NZC (67% and 63%) and NZ Māori (24% and 26%), and included all visitors and few Ngāi Tahu (5%

each). The poor-fair site and catchment scores were associated with Ngāi Tahu (40%, 33%) and NZC (60%, 67%).

The evaluation of Koukourārata differed to other study areas, but was similar between site and catchment (Figure 5.10 g-h). The site and catchment was ranked good-excellent by a higher proportion of NZC (76% and 87%), few Ngāi Tahu (6% and 7%), all visitors at the site (18%) and few at the catchment (7%). Most the poor-fair site and catchment scores were affiliated to Ngāi Tahu (43% and 67%), and similar proportion of NZC (29% and 17%) and NZ Māori (29% and 17%).

The statistical comparison of environmental evaluation between Ngāi Tahu and another cultural affiliation group was investigated (Table 5.10). The site and catchment scores given by Ngāi Tahu were significantly lower than NZC for all areas ($p<0.0001$ to $p<0.0005$). Ngāi Tahu scores were lower than NZ Māori at most areas ($p<0.0001$ to $p<0.005$) except for the site evaluation at Koukourārata. There was a significant difference between Ngāi Tahu scores and visitors at all sites, except Rakahuri/Ashley-SC were visitors declined participation in this survey.

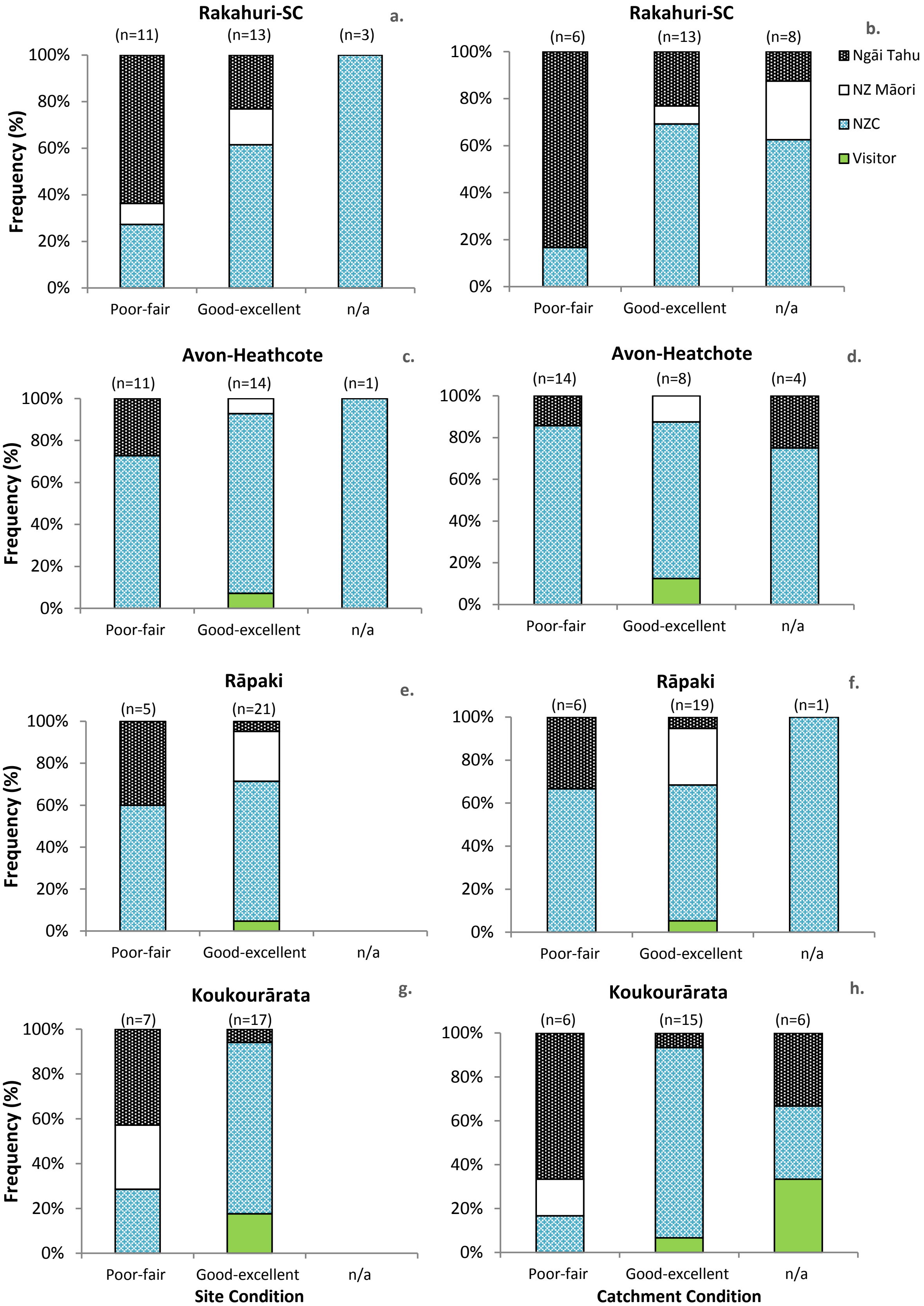


Figure 5.10. The rating value for environment condition for sites (left) and catchment (right) grouped by cultural affiliation for all participants (N=106). Area names are provided in Table 5.1.

Table 5.10. Fisher results of perceived environmental scale (poor-fair and good-excellent) for each area between Ngāi Tahu and other cultural affiliation groups (N=106). Significant values in bold, n.v. is no value, and area names are provided in Table 5.1.

Area and scale	**Cultural affiliation**							
	Ngāi Tahu comparison to each group:							
	NZC		NZ Māori		Visitors		Both (NZC and NZ Māori)	
	v²	p-value	v²	p-value	v²	p-value	v²	p-value
R-SC								
Site	32.73	**<0.0001**	10.77	**0.0015**	n.v.	n.v.	34.03	**<0.0001**
Catchment	64.84	**<0.0001**	22.83	**<0.0001**	n.v.	n.v.	71.90	**<0.0001**
AH								
Site	27.02	**<0.0001**	33.00	**<0.001**	33.00	**<0.001**	29.04	**<0.001**
Catchment	27.02	**<0.0001**	25.00	**<0.001**	25.00	**<0.001**	14.42	**<0.001**
R								
Site	23.54	**<0.0001**	50.02	**<0.0001**	21.78	**0.0001**	32.95	**<0.0001**
Catchment	15.12	**0.0001**	45.89	**<0.0001**	18.24	**0.0003**	23.45	**<0.0001**
K								
Site	48.22	**<0.0001**	3.80	0.0789	43.44	**<0.0001**	29.00	**<0.0001**
Catchment	94.97	**<0.0001**	1.72	**<0.0001**	36.22	**<0.0001**	9.06	**0.0031**

Environmental indicators

Participants provided environmental indicators that were associated with their site activities (Figure 5.11). There were 12 total environmental indicator groups formed from those provided, and five were most common between participant groups including sediment, water condition (quality and flow), contaminants (faecal, metals, safety), fish/shellfish life, and the presence/interaction of people with the environment. The other seven were: management in place (e.g., rāhui); land use/land cover; weather indicators, maramataka (Māori lunar calendar – a planting and fishing monthly almanac) and abiotic variables; harbour activities (e.g., dredging); sensory and local experience; bird life; and algae/seagrass.

The top five indicators (per area) that were common between participant groups, included:

- sediment:
  - good (4.5%-5.0% R-SC, 0-11.1% R, 9.1-10% K)
  - poor (16.7-20.0% R-SC, 16.7-38.5% AH, 22.7-33.3% R, 29.6-40.0% K).
- water condition:
  - good (15.0-36.4% R-SC, 30.8-33.3% AH, 0-33.3% R, 30.0%-45.5% K)
  - poor (20.0-27.8% R-SC, 0-15.4% AH, 9.1-33.3% R).
- contaminants:
  - good (0-25.0% R)
  - poor (0-11.1 R-SC, 38.5-50.0% AH, 22.7-33.3% R, 22.2-30.0% K)
- fish/shellfish:
  - good (13.6-50.0% R-SC, 16.7-30.8% AH, 11.1-25.0% R, 0-20.0% K)
  - poor (0-16.7 AH, 0-13.6% R, 0-11.1% K)
- and the presence/interaction of people:
  - good (0-5.0% R-SC, 7.7-16.7% AH, 11.1-25.0% R, 18.2-20.0% K)
  - poor (0%).

Ngāi Tahu participants commented on the lack of depth and value captured within the quantitative measurements of environmental condition. For instance, participants commented on the boundary between interactions with place was not only food safety, but cultural safety. For instance:

“The food standard doesn't provide an indigenous perspective of health standard. There is a boundary with poor environmental health” (Ngāi Tahu).

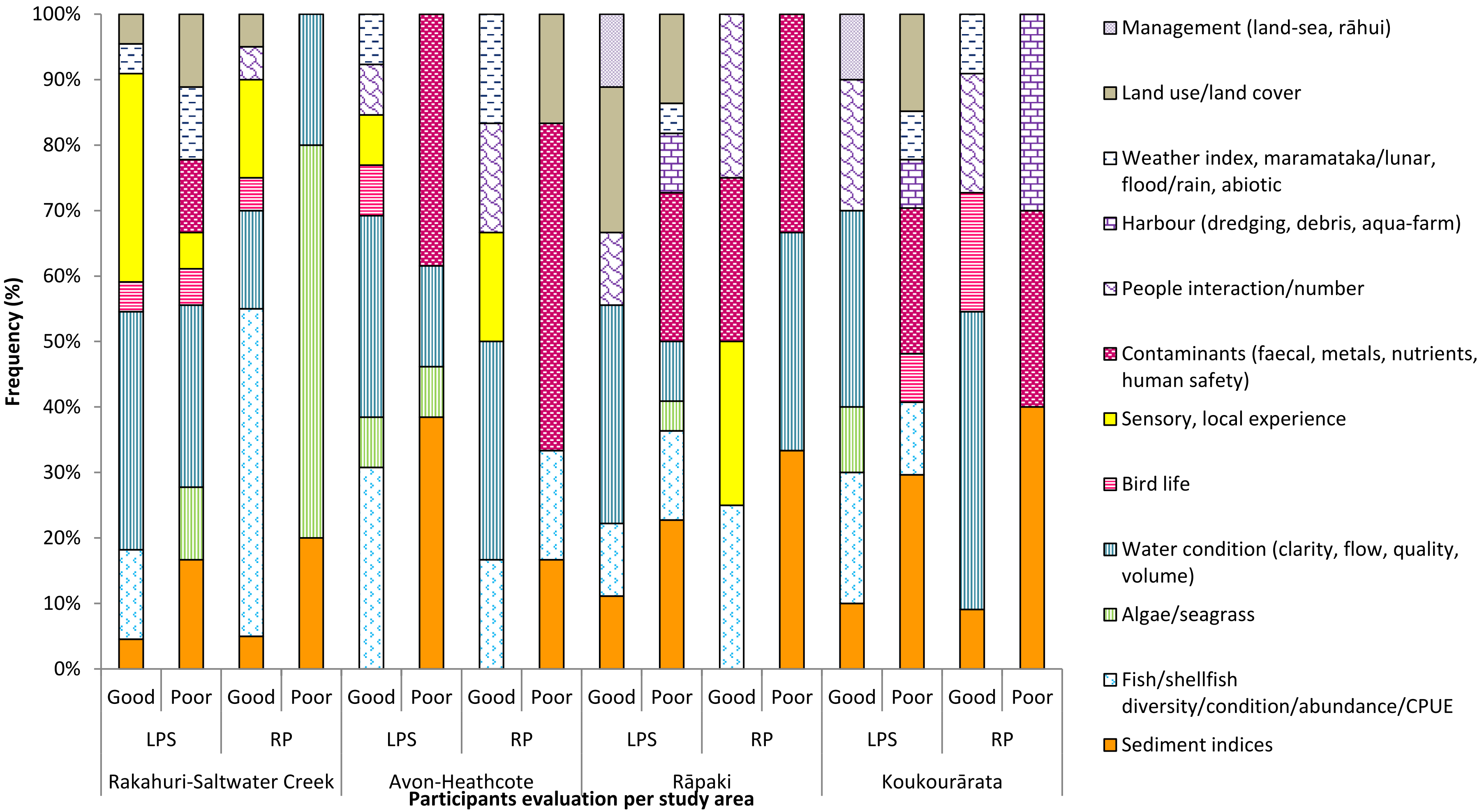


Figure 5.11. The percent frequency (%) of environmental indicator (good and poor) at each study area as evaluated by Local Practitioners and Specialists (LPS) and Recreational Participants (RP) (n=106). Area names are provided in Table 5.1.

Changes

Most of the Local Practitioners and Specialists (LPS; 20/23) and around half of the Recreational Participants (RP; 43/83) reported changes occurring over time (Figure 5.12). The most common change amongst sites were catchment land use (10.0%-14.5%), water quality (4.8%-15.4%), water flow (9.2%-13.3%), sediment (10.8%-15.6%), pollution (6.5%-10.8%), and earthquake impacts (1.6%-13.3%). Algae were perceived to change at Rakahuri/Ashley-SC (8.1%) and Avon-Heathcote Estuary (3.1%). The movement of the estuarine mouth and flooding were mentioned only at Rakahuri/Ashley-SC (each 4.8%,). Changes in bird life were reported at Rakahuri/Ashley-SC (4.8%), Avon-Heathcote Estuary (6.2%), and Rāpaki (10.0%), and changes in aquatic life at Rakahuri/Ashley-SC (9.7%), Avon-Heathcote Estuary (4.6%), and Koukourārata (13.3%, Figure 5.10). The perceived main change impact was significantly different amongst participant group (LPS>RP; H=29.01, DF=1, p<0.0001), experience (less experience<more years; H=30.84, DF=1, p<0.0001), between at least two location (R<K<AH<R-SC; H=13.27, DF=3, p<0.01), and between at least two cultural affiliation groups (Visitor<Māori<NZ European and Pacific<Ngāi Tahu; H=30.53, DF=3, p<0.0001).

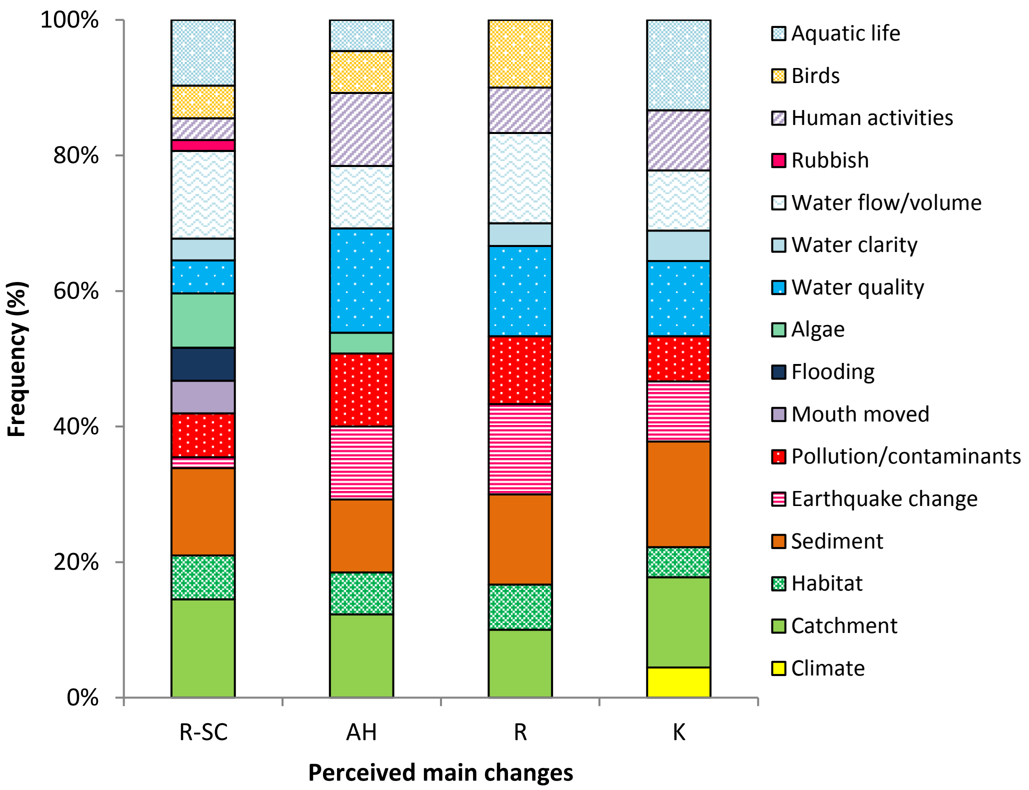


Figure 5.12. Frequency of perceived main changes that have occurred over time as provided by Local Practitioners and Specialists (LPS) and Recreational Participants (RP) at each area (n=106). Area names are provided in Table 5.1.

5.3.6. Correlation analyses

The perceived main changes scores (increases with impact score) were positively correlated with participant experience (r=0.61, p<0.0001, Table 5.11). Both the site and catchment scores (increases with good score) negatively correlated with participant experience (both with r=-0.39, p<0.0001). The main changes score also negatively correlated with both the site and catchment scores (r=-0.44, p<0.0001, r=-0.46, p<0.0001, respectively). The site and catchment score moderately correlated to each other (r=0.51, p<0.0001). There were no significant correlations between these socio-cultural indices and the perceived fishery abundances. The correlation table is provided within Appendix 5.1.

Table 5.11. Correlation between participant experience with the socio-cultural fishery and environmental scores. Significant values are in bold, potential significance italicised, as corrected by the Benjamini-Hochberg critical value (i/m*Q) (m=11, Q=0.05). The spearman coefficient (r) and p-value are given.

	Participant experience (years)			Main changes score		
Variables	r	p-value	Variables	r	p-value	(i/m*Q)
Main changes score*	**0.61**	**<0.0001**	Participant experience	**0.61**	**<0.0001**	0.005
Site score	**-0.39**	**<0.0001**	Site score	**-0.44**	**<0.0001**	0.010
Catchment score	**-0.39**	**<0.001**	Catchment score	**-0.46**	**<0.0001**	0.015
Enviro. Index**	*-0.26*	*0.04*	Enviro. index	*-0.26*	*0.04*	0.020
Galaxiids	-0.51	0.16	Galaxiids	-0.64	0.06	0.025
Clams and cockles	-0.34	0.18	Saltwater clams	0.50	0.07	0.030
Saltwater mussels	-0.45	0.31	Clams and cockles	-0.39	0.12	0.035
Flounder	0.05	0.87	Saltwater mussels	-0.49	0.26	0.040
Saltwater clams	0.02	0.94	Flounder	-0.25	0.44	0.045
	Site score			Catchment score		
Variables	r	p-value	Variables	r	p-value	(i/m*Q)
Catchment score	**0.51**	**<0.0001**	Site score	**0.51**	**<0.0001**	0.005
Main changes score	**-0.44**	**<0.0001**	Main changes score	**-0.46**	**<0.0001**	0.010
Participant experience	**-0.39**	**<0.0001**	Participant experience	**-0.39**	**<0.001**	0.015
Saltwater mussels	0.53	0.22	Clams and cockles	0.40	0.16	0.020
Saltwater clams	-0.35	0.23	Saltwater clams	-0.31	0.32	0.025
Flounder	-0.21	0.50	Flounder	-0.20	0.57	0.030
Clams and cockles	0.17	0.51	Saltwater mussels	0.17	0.72	0.035
Enviro. index	0.06	0.65	Galaxiids	-0.12	0.80	0.040
Galaxiids	-0.14	0.72	Enviro. index	0.02	0.88	0.045

*Main changes score is the total negative change score.
**Environmental index score: is the total positive condition score.

5.3.7. Management and Practices

All Local Practitioners and Specialists (LPS) and many Recreational Practitioner (RP; 61%) were familiar with the current estuarine management practices. Participants referred to fisheries and recreational regulations in general (22.7% LPS, 31.8% RP), specific regulations including bag/size limits (9.1% LPS, 27.3% RP), Ngāi Tahu papatipu rūnanga (including marae) (21.2% LPS, 6.8% RP), or agencies and their management plans including DOC and MPI[8] (16.7% LPS, 4.5% RP). Specific rules at Rakahuri/Ashley-SC included whitebait (6.8% RP), walking dogs and driving on site (1.5% LP, 2.3% RP). Both participant groups equally mentioned specific restrictions in place at Rāpaki and Koukourārata (e.g. rāhui 7.6% LP, 9.1% RP, and set netting 3.1% LP, 4.7% RP). The iwi management plan and cultural health index (7.6% LPS), the RMA (1.5% LP, 1.1% RP), and yacht rules (1.2% RP) were only referred to at the Avon-Heathcote Estuary. Knowledge of the local current management regulations (agreement/disagreement by participants) differed significantly amongst participant groups ($v^2 = 32.27$, DF=1.0, $p<0.0001$).

Most LPS (95.7%) and some of the RP (38.5%) responded to the question regarding estuarine management effectiveness. The LPS agreed that management was effective (43.5%), just over half of that number agreed to ineffective management (26.1%) or partially effective management (26.1%). Fewer RP agreed that management was effective (28.9%), a small number thought it was ineffective (4.8%) or partially effective (4.8%). The analysis of whether management was 100% effective (partially effective is considered outright ineffective) according to LPS and RP was significantly different ($v^2=9.02$, $p<0.01$). Agreement was associated with fishery regulations, areas for children, and a good community. Those who disagreed, were concerned with bag limits being too high, overfishing, management complexity (many agencies and no systems approach), and policing. Mana whenua referred to the changes in political and ecological variables when they discussed their hapū mahinga kai. The LPS had referenced wider systems management and the importance of public consent. Similarly, when analysing each estuarine area, the response of LPS and RP is significantly different at Rakahuri/Ashley-SC ($v^2=5.30$, $p<0.05$), Avon-Heathcote Estuary ($v^2=29.35$, $p<0.0001$), and Rāpaki ($v^2=32.28$, $p<0.0001$).

The response of LPS at Rakahuri/Ashley-SC were divided into two groups of those who perceived the boundary was similar to the past (42.8%) and those who disagreed (57.1%). At AH Estuary, most LPS disagreed (60%) than agreed (20.0%). Contrary to this, LPS at Koukourārata and Rāpaki mostly agreed it was the same (66.7% and 60.0%, respectively), compared to those who disagreed (16.7% and 40.0%, respectively). Very few RP responded to this question, some agreed there was no change (9.6%) disagreed (6.0%), or were not sure (7.2%). The response to the management boundary remaining constant over time was not statistically significant between participant groups at any area.

5.4. Discussion

The relationship between local people and the environment can often be indicative of the state of the environment. Peoples' perspectives of the environment are based on their values, established through experience, integenerational and ecosystem knowledge and cultural worldview. Waitaha estuaries are important locations for resident and migrating fauna, plant life, food systems, and cultural identity. The present study provides a multiple-value evaluation according to the cultural affiliation and experience of LPS (including long-term New Zealand Citizens and residents, NZC) and Recreational Participants (RP). Frameworks and assessment tools need to consider cultural-based methodologies when navigating cultural values and knowledge within environmental management (Kawelo 2008, Tipa and Nelson 2008, LEaP 2010, Chan et al. 2012, Harmsworth and Awatere 2013). This study distinguishes between LPS NZC and RP NZC as well as Mana whenua and Tangata whenua and it focusses on the main values associated with each estuary and how these may best guide ki uta ki tai management.

5.4.1. Traditional and current values

Each estuary area is highly valued by the local Waitaha residents. Most LPS who were affiliated to Ngāi Tahu and NZC referred to the the Ngāi Tahu hapū – who are Mana whenua - at each estuary. Those who were NZC also referred to the importance and heritage value of these estuaries for Canterbury residents. According to LPS the current value of place is referenced to the relationship between Ngāi Tahu hapū or extended whānau and the environment (Section 5.3.2). Mana whenua referenced their ancestral connection to place through tūrangawaewae and whakapapa. The hapū traditionally occupied specific geographic boundaries, and controlled a number of resources such as mahinga kai (including seafood gardens and other sources of food), specific fishing grounds, wetlands and forest lands (Mead 2003). In this study, hapū boundaries extended where possible from inland to coast, and utilised estuaries and coastal waters. Their tūrangawaewae and mahinga kai areas would include the catchment, connecting streams and the outer marine environment. This was historically recorded, as inland people who had the right of ownership to shore lands would move to fishing-stations to fish and collect shellfish (Best 1929).

Today, all four estuaries are valued highly by New Zealand local residents. Three of the four estuaries were highly valued by Mana whenua, but this value has dimished at the Avon-Heathcote Estuary/Ihutai (AH Estuary). No traditional function exists there currently, and due to multiple factors that occured in the 1960s (the drainage of mahinga kai, reserve compulsory acquisition and the beginning of treated sewage input) as shared within interviews (Section 5.1.1.). Ngāi Tahu iwi continue to evaluate the cultural and scientific values of this estuary, consistently finding poor CHI scores within the State of the Takiwā assessment (Pauling et al. 2007, Lang et al. 2012); however, there has been no improvement in CHI score between surveys due to the impact of infrastructure caused by the 2010 earthquake (Lang et al. 2012, McMurtrie 2012).

In addition to diminished Mana whenua values, the fishing practices of long-term RP who werenon-Ngāi Tahu were also impacted by poor water quality and the 2010 earthquake. Practices are area specific (fishing in more rural areas), site specific (fishing/gathering shellfish in the estuarine mouth and outer estuary), and fishery purpose (changing consumption behaviour). During this study one difference highlighted the different between Mana whenua (Ngāi Tahu) and non-mana whenua; and between long-term and short-term fishers. Within the AH Estuary, non-mana whenua fished and gathered for consumption and bait;, and specifically long-term RPs fished in the estuary for consumption but shellfish for bait, while only short-term RPs gathered shellfish for consumption. Prior to the removal of the discharge in 2010 and despite warning signs in place at this area, some Christchurch residents still collected seafood (Fisher and Vallance 2010). However, fewer people collected than in the past, many collected from the outer boundary of the estuary; indeed, most residents considered the area to be polluted and the shellfish unsafe to eat (Fisher and Vallance 2010). The 2010 survey noted that of the nine on-site informants, three of the four New Zealand Māori identified as Ngāi Tahu, three as Pākehā, one as Samoan and one person did not record their ethnicity (Fisher and Vallance 2010).

5.4.2. Activities and resources

Fishing, gathering of shellfish and non-inanimate resources, leisure and other activities such as monitoring, conservation/planting, ecological research, and kaitiakitanga were the main estuarine activities undertaken by LPS. The main RP activities such asincluded fishing, leisure, and other activities (bird and wildlife watching). Overall, more participants leisured and fished in rural locations than in urban locations, particularly when it came to direct contact such as swimming; however, walking dogs and on-water activities such as kayaking/waka ama/sailing were popular within the urban area of the AH Estuary and Koukourārata. It is difficult to review existing estimates of recreation value, especially in terms of the value of ecosystem services to recreation (Clough 2013). A water flow report showed that the Rakahuri-Ashley Estuary supported several beach activities such as vehicle driving, picnics, and sightseeing and fishing (including for whitebait and eels) (Mosley 2011). A number of beach-side (picnics, walking and bird watching), on-water (yachting, powerboats, rowing and canoeing), and outside-the-estuary (land-based sports clubs) activities have been popular at the Avon-Heathcote Estuary since the 1950s (Boyd 2010).

The LPS fishers had more specific target/favoured fishery species compared to RP and had more frequently witnessed changes in the relative abundance of species than less experienced fishers. The most frequent favoured or targeted living resources named by participants included fish (in general/no species identified), galaxiids, native and migrating birds, and three shellfish families (Section 5.3.4.). A range of fisheries, including galaxiids (inanga), were named by LPS and RP at Rākahuri/Ashley-SC, while 'fish' in general was most commonly mentioned by RP. However, inanga/whitebait fishing, an activity that takes place towards the Avon-Heathcote Estuary, was missed in this study- due to low numbers of fishers present to interview. This is likely due to the impact of earthquakes. The perceived abundance of only inanga and pātiki were frequent enough to compare across time periods. Both species were perceived differently by participant groups at Rākahuri/Ashley-SC (LPS<RP) and pātiki abundance was similar at Koukourārata. This implies that key shifts (declines) may have occured in the last 20 years. Similarly, local people across the South Island had commonly perceived that the access to important inshore seafood species had become more difficult over the participants lifetime with marked declined occuring from the 1970s (McCarthy et al. 2014).

Significantly more LPS than RP collected inanimate objects, many of which were affiliated to Ngāi Tahu. Non-Ngāi Tahu LPS collected inanimate objects in association with research and monitoring. Inanimate objects were associated with food, gardens, textiles, and ornamental purposes. Whakapapa and mauri was present within all aspects of the environment, including animate and inanimate objects. All things animate and inanimate have a whakapapa (Williams 2004, Harmsworth and Awatere 2013), explained in detail within Section 5.1.

Shellfish were favoured species by LPS compared to RP and were perceived as abundant, especially at rāhui sites, although tuangi was perceived to have declined at Rāpaki. A scientific survey comparing abundances of pipi at Rāpaki and tuangi at Koukourārata inside and outside the rāhui area showed that shellfish were more abundant and individuals were larger (including harvestable sizes) within the reserve than outside (Mudunaivalu 2013). In a public survey of the state of marine fisheries in New Zealand respondents perceived marine reserve fisheries to have stayed the same or improved, and while perceiving that outside these reserves the state of the fisheries had either not changed or it had worsened over the last five years (Hughey et al. 2016). During the course of this study, rāhui prohibited gathering shellfish at Rāpaki and cockles at Koukourārata.

Although this study found species to be abundant, LPS and RP did not gather at particular locations due to current environmental or sustainability concerns (when considering lifting of rāhui from mātaitai beds). In particular, the LPS gathered tuangi/cockles for consumption at two areas, the R-SC Estuary and when permitted at Koukourārata. The RP gathered tuangi at open sites: R-SC, AH Estuary, and (when permitted) Koukourārata. Warning signs for shellfish were present at the AH Estuary and warnings were issued regarding toxic algae within the Rakahuri/Ashley-Saltwater Creek Estuary. Co-development of a mahinga kai (species, site, and practice) tool towards indicators and environmental conditions towards cultural-based safety is advised. Estuarine and rocky shores are preferred for collecting shellfish (Smith 2013) and the overall objective of the customary mātaitai reserves in Rāpaki and Koukourārata is to protect the shellfish population in the intertidal coastal area (Mudunaivalu 2013). Marine invertebrates are of particular interest to kaitiaki along the east coast of Te Wai Pounamu, include pāua, crayfish, mussels, cockles and oysters (McCarthy et al. 2014). The importance of shellfish for Tangata whenua is captured historically within whakapapa:

> *"The mythical origin of shell-fish as given by the Maori is, like most of his origin myths, based on personification. We are told that Hunga-terewai, a descendant of Hine-moana, the personified form of the ocean, mated with another weird being, named Pipihura, their progeny being Kakara, Ngakihi, Toitoi, Pupu, Kokihi, Tio, Whetiko, Whetowheto, Kaiwhao, &c., all of which names pertain to shell-fish." (Best 1929)*

Wading birds are indicative of shellfish presence and healthy estuarine ecosystems (Bolton-Ritchie 2008, Mosley 2011, Bolton-Ritchie 2015). Native and migrating birds were observed by people from three of the areas. Positive remarks were made regarding native birds (such as tūturiwhatu/dotterels, torea/oystercatchers, terns, kōtare/kingfishers, korimako/bellbirds, spur-winged plovers, kotuku-ngutupapa/spoonbills and karoro/seagulls) while negative comments were made about geese. Canterbury estuaries support a wide range of birds, including the wading birds mentioned by participants (Jones et al. 2005, OSNZ 2010). Canterbury braided riverbeds are breeding grounds for the black-fronted tern (*Chlidonias albostriatus*), black-billed gull (*Larus bulleri*), banded dotterel (*Charadrius bicinctus*) (OSNZ 2010). The AH Estuary supports almost 2% of the world's population of variable oystercatchers (*Haemotopus unicolor*) and high numbers also present at Lyttelton Harbour (Crossland 2001).

5.4.3. Environmental condition

The perceived environmental condition varied according participant group, experience, and cultural affiliation (when Ngāi Tahu scores were compared to other affiliations). The results implied that RP generally affiliated to NZC and all visitors valued the sites as good to excellent for each estuary. The differences between local residents and visitors in this present study is supported by a nationwide survey regarding New Zealand's marine fisheries and management (Hughey et al. 2016). The perception of 'other' ethnicities (such as Pacific Islanders and Asian peoples) were almost always more positive than either NZ Europeans or Māori (Hughey et al. 2016).

Water is an important resource, regarded as a fundamental taonga by Māori and the health of water bodies is important for customary and social uses, and especially for mahinga kai. Within the current study New Zealand Māori environmental site scores agreed with Ngāi Tahu scores at Koukourārata, but Ngāi Tahu had poorer scores that New Zealand Māori at the Avon-Heathcote Estuary. Thus, there is a difference in iwi scores according to affiliation and experience. Māori are bounded by whakapapa and responsibilities are conferred upon descendants by past generations, who then also determine reponsibilities for future generations (Harmsworth 2005). All of the kaitiaki interviewed reinforced that they have an ancestral obligation, a responsibility as kaitiaki, with regard to their inshore fisheries (Dick et al. 2012). Additionally, the 'direct' food gathering involved with mahinga kai requires a pristine environment (Te Rūnanga o Ngāi Tahu 2004). Hughey et al.'s (2016) nationwide survey does not look at the diversity of local iwi-based knowledge, but it did suggest that Māori judged marine fisheries and their management to be poorer than did New Zealand Europeans (Hughey et al. 2016). However, that study did not acknowledge that differences in scores may be due to Māori having particular affinities with marine fisheries through traditional use, and Treaty of Waitangi recognition (Hughey et al. 2016).

Local long-term residency, experience and expertise were fundamental differences in this current study. The LPS and RP with greater experience who affiliated to Ngāi Tahu and NZCsimilarly scored Rāpaki and Avon-Heathcote as poor compared to other groups. Poor scores at other sites (Rakahuri/Ashley-SC and Koukourārata) were primarily given by Ngāi Tahu, showing that their cultural values were compromised. The number of years of participant experience was a significant factor in the correlation analysis of environment scores. Regarding society's perspective of natural resource management – the grouping of Māori, Pākehā and other non-Māori should be based on their relationship with a defined geographical area, as well as their expertise and knowledge. An important lesson is highlighted by Berkes (2009), who states that social-ecological memory is built by journeying and constantly interacting and that both long-term adaptations and recent coping responses are based on detailed knowledge of the environment. There are clear policy implications here, particularly for mana whenua (Ngāi Tahu), New Zealand Pākehā and citizens who are long-term residents who are involved and interact with these estuarine environments.

5.4.5. Environmental values

There were six main values drawn from the combined environmental condition comments and perceived indicators (Section 5.3.5.). This was useful as a calibrator of scoring, especially where participants' scores mismatched their comments. These values were based on holistic, sediment, water condition (flow, volume, and quality), contaminants (pollutants, sewerage/septic and human safety), earth quake effects, and fish/shellfish indices (diversity, condition and abundances). These are discussed below.

Holistic values

The value of place to New Zealanders who affiliate as European, Pākehā, Pacifica and Māori (non-mana whenua) draws on aesthetic and/or sensation qualities, for example, the terms ‘beautiful’, ‘love it’, ‘clear and pleasant’, ‘feels clean’, and ‘generally tidy’. Similar to other studies, estuaries also provided for cultural services, including cultural and spiritual heritage, recreational, aesthetic, and cognitive uses (Thrush et al. 2013).

Ngāi Tahu iwi and hapū were connected to place through whakapapa. Poorer scores from this group compared to non-Ngāi Tahu interviewees were reflections of the observation of degradation through their intergenerational relationship with the environment. Ngāi Tūāhuriri no longer interacted with the AH Estuary in a traditional manner. The overall Cultural Health Index score within the State o the Takiwā assessment indicated that NZ Māori would not return to this site in future (Pauling et al. 2007).

While there are many intangible qualities associated with holistic values, there are elements of physical estuarine processes (Thrush et al. 2013), and physical conditions that Ngāi Tahu use as indicators (Tipa and Teirney 2003, Te Rūnanga o Ngāi Tahu 2004, EC 2011). Similar to previous findings, the current study’s indicators of environmental condition included mahinga kai, indigenous flora and fauna, water flow and river to the sea management (Tipa and Teirney 2003, Te Rūnanga o Ngāi Tahu 2004, EC 2011). According to Lang et al. (2012), the The majority of sites contained high pollution levels and were unsafe for mahinga kai and in some cases were also unsafe for swimming.

Sediment

Indicators of poor sites and catchments included sedimentation, silt/plumes/declined shingle, dark mud, state of run-off and turbidity. In addition, sediment had been observed to impact favoured fishery and shellfish. Tuangi, tio, and inanga eggs were perceived to be smothered by silt, and shellfish filter feeding was impaired. In an ecological survey of Koukourārata interviewees had observed many dead or dying rock oysters in the upper harbour, the poor state of the cockle bed, smelly black mud and silt and areas becoming shallower (Hepburn et al. 2011). The Rakahuri/Ashley-SC waterways were known to be particularly affected by pastoral agriculture with its attendant runoff of both natural (faecal matter) and artificial fertilisers (Adkins 2012). In the same area sediment transport and river bed levels are affected by channel construction at bridge crossings, flood and river activities and gravel extraction for commercial and river control purposes (Mosley 2011).

Kaitiakitanga embraces social and environmental dimensions, not only ‘guardianship, and stewardship’ but also ‘resource management’ (Wright et al. 1995, Kawharu 2000). Ngāi Tahu kaitiakitanga also included māra mātaitai. In the present study interviews, Ngāi Tahu participants found cockles thrived when re-seeded and translocated into mixed sediment habitats such as shingle/sediment/light mud. The NZC LPS also mentioned translocation experiments as being successful for tuangi at Rakahuri/Ashley River-Saltwater Creek, but unsuccessful at Rāpaki. Re-seeding and translocations have long been practiced by Ngāi Tahu iwi (Waitangi Tribunal 1987, Tau et al. 1992) e.g. pipi and cockles have previously been seeded near the stream mouth (Tau et al. 1992). Research has shown that the transfer of adult stock may be the most promising technique for restoration of tuangi (Marsden and Adkins 2010, Adkins 2012).

Water condition

Water clarity, flow, and volume were associated with natural events (e.g. seasonal cycles and earthquakes), land-use and cover (e.g. agricultural or riparian) and anthropogenic influences (e.g. drainage and water abstraction). Increased run-off and sedimentation was noticeable with heavy winter rains in more rural areas – and scored poorly where there was little to no native plant life in the catchment, riparian zone or estuary itself. Many participants avoided fishing or gathering shellfish in winter, and the activity of LPS was primarily seasonal. Sites in Te Wai Pounamu streams were similarly high scoring due to intact native riparian buffers, a lack of modification or pressure on the margins (land use/land cover) and, in comparison to low scoring sites, no perception of sources of discharges and pollution (Pauling 2008).

Summer was the most popular time for RP to visit these estuarine areas, although water conditions were perceived poorly at Rakahuri/Ashley River-SC and Avon-Heathcote Estuary during this time. Changes in water volume were perceived at both estuaries and interviewees felt safer nearest the mouth. The Rakahuri/Ashley-SC Estuary in particular had high risks of proliferation of cyanobacteria associated with lower water volume and flow, which impacted swimming, shellfish gathering and dog safety. Long-term locals no longer collected in more riverine areas and few collected near the mouth or outside the estuary. The natural flow regime of Rakahuri/Ashley river is modified principally by resource consents to abstract water directly from the river, its estuaries and groundwater (Mosley 2011). A combination of factors including, changes to riparian margins, increased nitrate and fine sediment loads, and alterations in flow regimes are likely to have contributed to the rise in proliferations of *Phormidium* sp. (a dominant genus of cyanobacteria) (McAllister et al. 2016).

Within this current study, the activities of local people were dependent upon and in some cases impacted by environmental conditions at each estuary. Contrary to the findings of Mosley (2011), recreational activities at Ashley were dependent on the presence of water. Recreational use of the Avon-Heathcote Estuary varied temporally according to ecological condition (Boyd 2010). Fundamentally, those who practice kaitiakitanga, linked human health and wellbeing to environmental health (Dick et al. 2012).

Contaminants and earthquake effects

Animal and human effluent (including avian and ruminant sources), septic tanks and sewerage pipes were all risks factors mentioned by gatherers and those who those who enjoyed swimming, wading and on-water activities. Contaminants were of concern at the Avon-Heathcote Estuary, Rāpaki and Koukourārata. In support of this current study, Koukourārata locals had previously raised concerns about septic tank runoff and pollution (Hepburn et al. 2011). Ngāi Tahu have raised multiple concerns with contamination in Te Pātaka a Te Rākaihautū/Banks Peninsula, including soil erosion, nutrient run-off and the effect of sewage on water quality (Tau et al. 1992).

Ngāi Tahu LPS reported that no one they knew harvested from the Avon-Heathcote Estuary, while none of the RP were affiliated with Ngāi Tahu. Experienced RP gatherers who identified as NZC ceased to consume shellfish from within the estuary but continued to fish. Due to the importance of water and mahinga kai, it is unacceptable to discharge sewage into waterways where food is collected (Tau et al. 1992). Most recently, the rāhui in Rāpaki Bay was extended due to poor water quality (and subsequently food safety risks) following the earthquakes (MPI 2016). The evaluation panel for the State of the Takiwā in AH Estuary were most concerned about the contamination from human and agricultural sources (Pauling et al. 2007).

Contrary to the concerns above, less experienced RP and visitors to New Zealand surveyed in this study continue to gather shellfish in the Avon-Heathcote Estuary, despite the presence of warning signs. In support of this, a previous survey recorded that nine people on-site harvested shellfish and fish from this area despite knowing the food risks, while two knew of people who had been affected by an allergic reaction or food poisoning from shellfish from the area (Fisher and Vallance 2010). Fisher and Vallance’s (2010) research was conducted prior to the new ocean outfall pipe and removal of sewerage from the estuary, as well as prior to the September 2010 earthquake.

An important consideration for all sites is the earthquakes of September 2010, February 2011 and June 2011, which devastated Christchurch City, homes and the environment. The impacts of the earthquakes are directly related to the contaminant indicator (above) as water quality, aquatic organisms (from liquefaction) and recreational amenities, infrastructure and access were all damaged. Shellfish gathering was impacted for half of the long-term RP fishers at the AH Estuary, though less experienced RP and visitors continued to harvest, following the earthquake. Within a nation-wide survey New Zealanders perceived sewage and storm water as a main cause of damage to marine fisheries and marine reserves (Hughey et al. 2016). The State of the Takiwā reported the Avon and Heathcote rivers in a degraded state before and after the earthquake (Pauling et al. 2007, Lang et al. 2012), with recreational water quality scores exceeded in the Avon (ESR 2012). Since 2013 when the current research commenced, smaller earthquakes have continued to be felt in these areas. The effects of the earthquake are considered within the ecotoxin analysis in the following chapter.

Fish and shellfish values

Fish and shellfish values were site-specific and key resource indicators included biodiversity, native/exotic resources, condition, catch-per-unit-effort (CPUE), size and abundance. An important consideration was raised that the holistic nature of kaitiakitanga suggests that it would be unwise to rely completely on a single-species approach, just as critics of the indicator-species approach by ecologists have cast doubt on its utility for environmental health monitoring (Schweikert et al. 2013). Such lessons are well documented in TEK/IK projects mostly with northern Canadian groups (Berkes 2009) and within fisheries science (Botsford et al. 1997), for example biodiversity and landscape conservation for subsistence and cultural values (See Berkes 2009).

Site specific environmental factors were evident in shellfish gathering by long-term shellfish gatherers. For example, Ngāi Tahu gatherers generally preferred gathering tuangi nearest the estuarine mouth, or saltwater clams (pipi/taiwhatiwhati) outside the estuary. These preferences were based on size, condition, abundance/CPUE, and food safety. The relative abundance of favoured fisheries was discussed earlier (Section 5.4.3.). Within a coastal study, fishery catch and measurements were utilised to explain changes over time, suggesting declined values over time (McCarthy et al. 2014). Additionally, within this study food safety included cultural-based environmental indicators (habitat change, sensory, surrounding land-use). Food gathering involved with mahinga kai requires a pristine environment (Te Rūnanga o Ngāi Tahu 2004).

5.4.6. Management and Practices

More LPS than RP participated in discussions around the current management and practices and the effectiveness of that management. Fishery regulations and policing received mixed reviews, and there were two circumstances where the fishery rules were either not known or not followed (personal observation 2014). However, the majority of participants followed rāhui in the mātaitai reserve and general fishery regulations outside of these areas. The cultural assessment of mātaitai reserves indicated shellfish indices were perceived positively by kaitiaki (Mudunaivalu 2013).

It appears that TEK is not included or enabled as an adaptive approach by local decision-making groups (iwi, environmental trusts or mātaitai committees) towards natural resource management in these estuaries. Ngāi Tahu proposed a concerted effort towards the conservation and protection of indigenous vegetation for their own sake, and as a habitat for native life such as birds, to control for erosion and fertiliser run-off (Tau et al. 1992). There are examples in New Zealand that support dialogue and partnership between science and traditional knowledge (Moller et al. 2009a, Moller et al. 2009b, Moller et al. 2009c). Some traditional knowledge and management systems use local ecological knowledge to interpret and respond to environmental feedback in order to guide resource management (Berkes et al. 2000a). Although customary marine/estuarine management tools exist, the power of resource management decision making has resided entirely with the Crown, who are reluctant to allow for decisions within an Indigenous paradigm or to share power with Tangata whenua (Taiepa et al. 1997, Morgan 2004, Tipa and Welch 2006, Jackson 2011).

This section is further discussed in combination with the ecological indices of shellfish in the following Chapter 6.

5.4.7. Summary

This research compared people's perceptions of environmental values in four Canterbury hāpua/estuaries. These values and perceptions differed according to participant group, experience and cultural affiliation. All of the estuaries were highly valued by local residents for their social, ecological and cultural qualities. The LPS confirmed that the Avon-Heathcote Estuary is not valued in a traditional manner by Mana whenua.

Favoured resources included shellfish species (tuangi/cockles, kūtai/mussels, pipi and taiwhatiwhati), fish (inanga/whitebait) and the observation of birds in general. Many RP did not target specific fish species compared to LPS, and less experienced participants did not evaluate fishery abundance. Most species were perceived to have declined, except kūtai and tuangi at Koukourārata and pipi at Rāpaki. Kūtai were cultured and available along the rocky shore at Koukourārata, while tuangi and pipi were protected by rāhui. Conversely, tuangi abundance was perceived to have declined at Rāpaki rāhui.

Overall, several environmental indices (contaminants/food safety, sediment, water conditions/quality and weather indicators/abiotic/maramataka) whakapapa/family based connection (including 'kiwi' beach culture) and restirctions (e.g. warning signs, long-term rāhui), were the key factors governing interaction of LPS and RP (short and long term), with each of the estuaries. Fishing, wading, food safety and cultural-based health from a Ngāi Tahu perspective were poor within the Avon-Heathcote Estuary. Although the Avon-Heathcote Estuary was unsafe, less experienced RP in this collect shellfish, although 50% of current long-term RP who gathered shellfish now used them as bait rather than food. A higher number of direct contact activities were conducted by LPS (e.g. gathering of shellfish and inanimate resources). There were site-specific concerns at Rakahuri/Ashley-SC, including sediment composition degradation, smell from surrounding farms, and toxic algae.

Ngāi Tahu individuals and more experienced New Zealand Citizens (NZC) score site environmental conditions more poorly than did other cultural groups. The scores of Ngāi Tahu at each of the areas showed their values were compromised more often than other affiliations. New Zealand Māori scored similarly to Ngāi Tahu at Koukourārata, but differently at other areas. Less experienced NZC and visitors scored conditions higher at most estuarine areas. The qualitative comments associated with the quantitative environmental scores above provided epth to this analysis and they highlighted additional environmental concerns.

The combination of scores, comments, and perceived indicators was a useful filter of important values. Key measurements of the environment included holistic values, sediment, water flow and water quality, contaminants, earthquake, and fish/shellfish indices. There were also similarities in ecological perceptions within both LPS and RP groups. Furthermore, this study supports and illuminates the importance of recognising Māori as embracing a wide range of views on many issues in common with Pākehā and other non-Māori groups (Harmsworth 2005).

Current fishery management wasdiscussed by LPS more than by RP. Most RP valued an area that supported their recreational values, including safety to wade in waterways. The LPS participants were more concerned with the management approach, the lack of integration between agencies and ecosystems, and the scarcity of input from the public. In addition, Ngāi Tahu participants were concerned with the ecological and political impacts to the study areas, especially mahinga kai. Mahinga kai and taonga are particularly guaranteed to the protection of Ngāi Tahu within the Kemps Deed and Te Tiriti o Waitangi and certain sites within this study appear compromised in this regard. The ecological impacts to mahinga kai have been a concern for a long period (See Tau et al. 1992, WT 1995). The environmental values of groups who have long-term affiliations with these areas show signs of degraded environments. Marine researchers and resource managers may put fishery resources at risk or unnecessarily compromise resource users' values by ignoring fishers' ecological knowledge (Johannes et al. 2000).

Environmental management needs to consider its framework when incorporating multiple values and knowledge systems. Indigenous knowledge systems seem to build holistic pictures of the environment by considering a large number of variables qualitatively, while science tends to concentrate on a small number of variables quantitatively (Berkes and Berkes 2009). Both approaches are important (Berkes 2009). The integration of TEK within resource management processes forces Indigenous People to express themselves in ways that conform to the institutions and practices of state management rather than to their own beliefs, values, and practices (Nadasdy 1999). Instead, a collaborative approach with dialogue and partnership is recommended (Moller et al. 2009a, Moller et al. 2009b, Moller et al. 2009c).

Chapter 6 The ecological values of shellfisheries in Aotearoa New Zealand

6.1. Introduction

Estuarine bivalves are exposed to multiple anthropogenic pressures in Canterbury, raising concerns regarding sustainability, food safety, and wellbeing. The water quality standards for recreational contact and shellfish gathering have been exceeded in Canterbury, including at the four present study areas (Figure 6.1): Saltwater Creek Estuary, Avon-Heathcote Estuary/Ihutai, Te Whakaraupō/Lyttelton Harbour: where Rāpaki Bay and Koukourārata/Port Levy are (Adkins and Marsden 2009, Bolton-Ritchie 2011, Lang et al. 2012, Bolton-Ritchie 2016). Permanent signage around the Avon-Heathcote Estuary warns the public about consuming shellfish due to potential contamination from past industrial input and treated wastewater. A preliminary investigation of shellfish tissue metals at Saltwater Creek Estuary also exceeded acceptable levels for human consumption (Adkins and Marsden 2009). Contaminant concentrations are particularly of growing concern as they affect food safety and socio-cultural wellbeing (Adkins and Marsden 2009, Fisher and Vallance 2010, Phillips et al. 2011, King and Lake 2013).

Tuangi/cockles (*Austrovenus stutchburyi*), pipi (*Paphies australis*) and tio/dredge oysters (*Tiostrea chilensis*) are important species to Mana whenua and long-term New Zealand citizens of the Canterbury region (Chapter 5). Bivalves, including these species, provide essential ecological services, are part of the food web, and facilitate the establishment of complex communities (Coen and Luckenbach 2000, Bolam et al. 2002, Dame 2011). For instance, filter feeding is one of the most ecologically significant features of aquatic environments and facilitates benthic-pelagic coupling as well as influencing water quality (Dame 2011). Many of our estuaries have been classified as vulnerable due to moderate to severe declines in ecological function (Holdaway et al. 2012). Therefore, further impacts to estuarine bivalves threatens ecosystem functioning (Sandwell et al. 2009, Dame 2011).

Long-term harvesters, especially Mana whenua and kaitiaki highlight perceived shellfish decline and environmental degradation (Chapter 5). The first *A. stutchburyi* survey across Canterbury estuaries showed densities were site-specific, with some sites having densities comparable to impacted estuaries in the North Island (Adkins 2012). Cockle density was lower at Koukourārata pā (Adkins 2012), which did not appear to be improving after an extensive closure period (Voller 2003, Marsden 2005, Adkins 2012). The first study of pipi at Rāpaki, showed densities were viable to support customary harvesting (Mudunaivalu 2013) but not recreational harvesting. Both Rāpaki and Koukourārata mātaitai reserves have rāhui in place (MPI 2016), the latter of which has been in place since 1995

(Marsden 2005). Compared to multiple *A. stutchburyi* beds across Canterbury, the Koukourārata rāhui bed was a cause for concern due to the very low abundances (Adkins 2012).

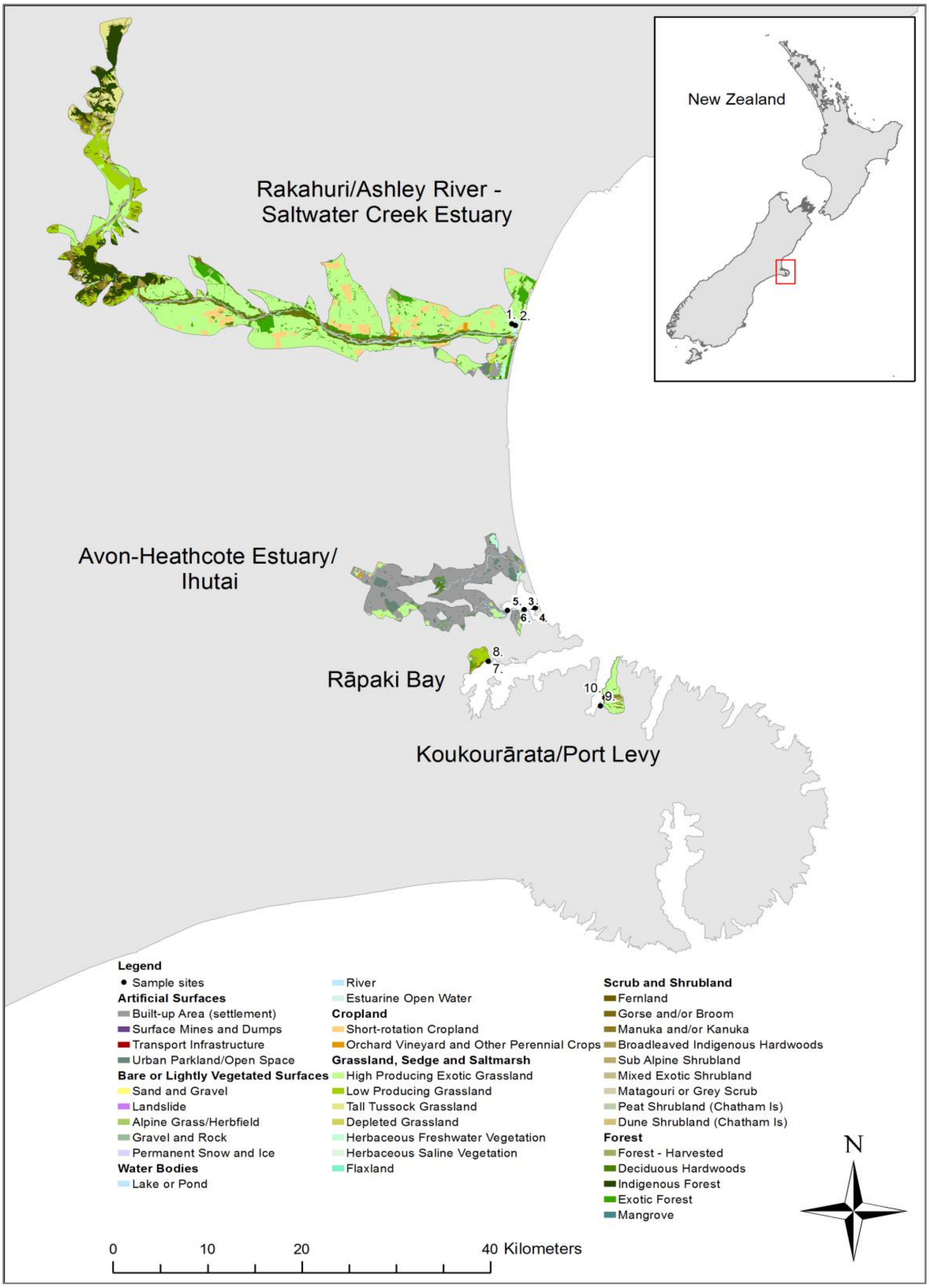


Figure 6.1. Map of the Canterbury study catchment areas and shellfish sites (numbered), the location in New Zealand (inset), and the 2012 land cover data base classification (LRIS 2012, Canterbury Maps 2015, LINZ 2015). The shellfish site names are provided in Table 6.2.

Waterway contamination is an issue in Canterbury, both in Christchurch City (Pattle Delamore Partners 2007, Pauling 2008, Christchurch City Council 2009, Moriarty and Gilpin 2009) and in rural areas (Bolton-Ritchie 2011, Environment Canterbury 2017, LAWA 2017). Across Te Wai Pounamu/South Island, *E. coli* levels in only two out of seventeen freshwater sites met the guideline level (Pauling 2008). Using nation-wide data, water quality and *E. coli* concentrations varied widely within land-cover classes, with lower quality in the pastoral and urban classes than in the native and plantation forest classes (Larned et al. 2004). The present study included rural and urban landscapes (Figure 6.1-6.2).

Estuaries are also at risk from raw sewage contamination due to earthquake damage to infrastructure that occurred in September 2010, February 2011, and June 2011. During the Canterbury earthquakes the Avon-Heathcote Estuary waterways experienced elevated faecal indicator levels (McMurtrie 2012) and degraded standards of Cultural Health Index (Pauling et al. 2007, Lang et al. 2012). The rāhui at the Rāpaki mātaitai reserve was extended due to food safety concerns. Since the commencement of this research in 2014, extensive infrastructure repair has continued around the city, as have smaller earthquakes.

Continued land development negatively impacts estuarine environments due to increased sedimentation (Kennish 1997, Thrush et al. 2004, Stewart et al. 2014). Silt and run-off can limit the distribution of bivalves, such as pipi and cockles (Stephenson 1981, Cummings et al. 2002, Booth and Cox 2003, Hewitt et al. 2008). Bouma et al. (2001) have suggested that juvenile settlement responds to stressors such as sediment dynamics. Silt composition and sediment metal concentrations are associated with poorer settlement of small *A. stutchburyi* and silt composition has been correlated with higher sediment-bound contaminants (McConway 2008). Within the Wadden Sea, the lower-intertidal zone was shown to recruit higher numbers of larval cockles before they moved to higher parts of the tidal flat (Günther 1991) compared to greater numbers of juveniles higher in the intertidal zone (Bouma et al. 2001). Very little is known about the shellfish populations within the lower-intertidal zone.

Shellfish contaminant concentrations and physiology (e.g. condition index: CI) can be influenced by weather, seasons and salinity. For example, in Whangateau Harbour, northeastern New Zealand, a seasonal trend of enterococci (faecal bacteria) was detected in the tissue of *A. stutchburyi* and another shellfish species, *Macomona liliana*, which illustrated maximum contamination correlating with higher winter rainfall (De Luca-Abbott et al. 2000). Similarly, in Te Whakaraupō, Canterbury, water quality for contact recreation as indicated by enterococci concentration, exceeded at particular sites during rainfall periods in summer 2011-2012 (Bolton-Ritchie 2012). The CI of *A. stutchburyi* has also shown seasonal patterns (Marsden and Pilkington 1995) however, this was not observed across multiple estuaries in Canterbury (Adkins 2012). Both studies showed CI was positively related with salinity (Marsden and Pilkington 1995, Adkins 2012).

6.1.1. Present focus and study species

New Zealand estuaries contain several highly valued bivalve species including the endemic *A. stutchburyi*, *P. australis*, and *T. chilensis* (Table 6.1). Shellfish decline and environmental degradation in Canterbury, perceived by Mana whenua and long-term recreational harvesters is a major concern (Chapter 5). This is the first study to investigate the relationship between these three bivalve species and the influences of their ecosystems, including land use, abiotic factors (salinity, grain size) and contamination (trace metal and *E. coli*) within the lower intertidal zone.

Table 6.1. Common, scientific, and synonymous names of the study species.

Name and species	Family (in bold) and synonymous names
Tuaki/tuangi/huangi, cockle, New Zealand littleneck clam. *Austrovenus stutchburyi* (Gray, 1828)	**Veneridae.** *Protothaca crassicosta* (Deshayes, 1835), *Chione aucklandica* Powell, *Chione stutchburyi* (Wood 1828). Tuaki at Rāpaki and Te Muka (Beattie 1994).
Pipi/roroa/taiwhatiwhati *Paphies australis* (Gmelin, 1791)	**Mesodesmatidae.** Wedge-shaped surf clams. Roroa, *P. australis*, from Rāpaki, pipi from North Island, and taiwhatiwhati in Otago (Beattie 1994).
Tio, dredge oysters *Tiostrea chilensis* (Hutton, 1873)	**Ostreidae.** Dredge oyster, Bluff oyster, or rock oyster. Formerly *Ostrea lutaria* and *Tiostrea lutaria* (Hutton, 1873), which was synonymous with the Chilean oyster *Tiostrea chilensis*, and by priority designated *T. chilensis* (Buroker et al. 1983, Matthiessen 2008).

The lower intertidal zone is commonly harvested for shellfish consumption. All kaitiaki interviewed by Mudunaivalu (2010) indicated that the lower zone and shallow subtidal area have the highest density of mature pipi, and that most harvesting occurs in these areas. It is only within the last 20 years that pipi were recorded scientifically in the subtidal zone (Hooker 1995). Evaluating these areas supplements the socio-cultural findings from Chapter 5 and provides an assessment of food safety in the harvest areas.

This study builds upon existing research of population ecology, sustainability, contaminants, and restoration, that have primarily focused on the dominant species *A. stutchburyi* (Marsden and Pilkington 1995, Adkins 2012, Marsden et al. 2014) and less so on *P. australis* (Mudunaivalu 2013). There is no local research on *Tiostrea chilensis*, and little has been done elsewhere in New Zealand

(Nielsen and Nathan 1975, McEntyre 1996). Many studies have focussed primarily on the Avon-Heathcote and Saltwater Creek Estuaries (Marsden and Pilkington 1995, McConway 2008, Marsden et al. 2014). Contaminant monitoring has also undertaken for both *A. stutchburyi* and *P. australis* within the Avon-Heathcote Estuary, while *A. stutchburyi* has also been monitored in Saltwater Creek Estuary (McMurtrie 2010, Bolton-Ritchie 2011, McMurtrie 2012, Bolton-Ritchie 2016). These two estuaries are included within this current study, along with Rāpaki and Koukourārata.

Austrovenus stutchburyi, or tuangi/tuaki, is from the bivalve family Veneridae and is known commercially as the New Zealand Littleneck Clam (Table 6.1). Tuangi is economically, ecologically and socio-culturally important (Larcombe 1971, Morton and Miller 1973, Marsden 2004). This species can be found across the country (Powell, 1979), living in soft mud to fine sand of sheltered shallow coastal and estuarine waters (Larcombe 1971, Marsden and Pilkington 1995). The shells, both living and dead, are used as a substrate by a variety of animals and plants, for attachment, grazing, or boring (Larcombe 1971). *A. stutchburyi* is a useful bioindicator species of trace metal (Peake et al. 2006) and faecal concentration (De Luca-Abbott et al. 2000) and is located across multiple estuaries in Canterbury (Adkins 2012)

Austrovenus stutchburyi are sexually mature at about 18 mm shell length, and become legal to commercially harvest at 30 mm shell length. It is predicted that this species reaches 30-35 mm in shell length within 6 to 12 years, depending on location (Irwin 2004). Movement of smaller individuals (< 25 mm in length), classednon-commercial and juveniles), has been observed to be extensive, but rare in larger individuals (≥25 mm in length) (Larcombe 1971, Stephenson 1981).

Paphies australis, or pipi, is from the Mesodesmatidae family and is restricted to sandbanks and harbour mouths in low estuarine intertidal channels with coarser sediments and strong tidal flows (Morton and Miller 1973, Morrison et al. 2009). There is a limited number of studies on pipi and these have primarily focussed on its biological and ecological aspects (Grange 1977, Hooker 1995, Hooker and Creese 1996), trace metal concentration (Nielsen and Nathan 1975), and more recently, population surveys (Mudunaivalu 2013, Pawley et al. 2013, Berkenbusch et al. 2015) and customary management (Mudunaivalu 2013).

Rāpaki Beach has the most significant pipi population in the Canterbury region and is one of the only few places in the South Island that this species is found in substantial numbers (Mudunaivalu 2013). *Paphies australis* is sensitive to environmental conditions and habitat structure (e.g. changes in silt) and nutrition (Mudunaivalu 2013, Pawley et al. 2013, Berkenbusch et al. 2015). In the past, site-specific declines of *P. australis* in Northland and Canterbury have been associated with changes in environmental conditions, changes in sediment, and/or physiology (Mudunaivalu 2013, Pawley et al. 2013).

Tiostrea (*lutaria*) *chilensis*, known commercially as either dredge oysters or Bluff oysters, is also widely distributed across the country. This species forms a significant portion of the fauna living higher in the intertidal rocky shore zone (Buroker et al. 1983) and forms conspicuous clumps along the rocks at Koukourārata/Port Levy (Marsden 2005).

Shellfish species are managed under the Quota Management System; specifically, the maximum number of shellfish (bag limit) is regulated by the Fisheries Regulation 1996 Section 19. There is no minimum legal harvest size for *A. stutchburyi* and *P. australis* (MPI 2016), but the estimated preferred harvest size for *P. australis* by recreational harvesters is ≥50 mm (MPI 2014). The legal harvest size of *T. chilensis* for recreational users in the South-East fisheries is >58 mm (MPI 2016), while ≥50 mm is the commercial landing size (Fu 2013). The size classes utilised in this study are provided in Section 6.2.2 (Table 6.3).

6.1.2. Objectives

The chapter objective was to evaluate the ecological indices of shellfish in the lower-intertidal zone of four Canterbury estuaries. The specific objectives of this chapter were to:

1. Evaluate the current densities, population structure and condition index of *A. stutchburyi*, *P. australis* and *T. chilensis* across four estuaries and to compare these with previous data.
2. Determine the concentrations of tissue and sediment contaminants (trace metals and *E. coli*) and to compare this with previously gathered local and global data. To evaluate the risks to shellfish populations and the health risks of consuming shellfish.
3. Calculate the Land Development Intensity (LDI) index for each catchment associated with the shellfish site.
4. Determine the association between catchment LDI and shellfish indices and contaminants.
5. Combine the shellfish ecological findings along with the socio-cultural value findings (Chapter 5) to better inform fisheries' management decisions.

6.2. Methods

This section provides the research methodology unique to the shellfish ecology and evaluation that is the focus of this chapter. The detailed methodology of landscape development scores, trace metal, CI, and sediment composition analysis are provided in (Section 2.3-2.4, Chapter 2).

6.2.1. Study areas

The ecological characteristics of cockles (*A. stutchburyi*), pipi (*P. australis*) and dredge-oysters (*T. chilensis*) were surveyed in the lower intertidal zone of four estuaries: Saltwater Creek Estuary; Avon-Heathcote Estuary/Ihutai; Rāpaki Bay; and Koukourārata (Figure 6.1, Table 6.2 and Figure 5.2-5.3 in Chapter 5). There is existing bivalve population research within these areas (Marsden 2005, Adkins 2012, Mudunaivalu 2013). The sites were chosen to represent catchments with varied land use, physico-chemical condition, and management regimes, including areas of concern (Koukourārata pā) to local kaitiaki (Personal communication, 2013). The full descriptions of these areas were provided in Section 5.1.1, Chapter 5.

The shellfish management regime is briefly noted here; Saltwater Creek is currently open-access, the Avon-Heathcote Estuary has signage warning against human consumption, and mātaitai reserve with long-term rāhui in place at Rāpaki and Koukourārata. A total of ten shellfish sites were selected (Table 6.2). *Austrovenus stutchburyi* was the primary target species due to higher availability and replicable site conditions, with eight sites (SCR, SCM, PJ, T, H, B, R beach, K pā). The *P. australis* population was a dominant species at Rāpaki beach (Mudunaivalu 2013) and included alongside *A. stutchburyi* surveys. The *T. chilensis* population were surveyed along Rāpaki and Koukourārata rocky shore.

Table 6.2. The contaminant study design for sediment and shellfish tissue analysis from 10 sites and the number (n) of samples tested. Site numbers are illustrated in Figure 6.1.

Study Area and catchment	**Sites**	**Shellfish tissue**		**Sediment**
		Trace metal (n=6 individuals)	*E. coli* (n=1 x 150g)	Trace metal (n=3 inidividuals) and *E. coli* (n=1 x 150g)
Rakahuri/Ashley-Saltwater Creek Estuary				
Saltwater Creek catchment	1. SCR: Saltwater Creek River	*A. stutchburyi*	*A. stutchburyi*	Yes
	2. SCM: Saltwater Creek Marine			
Avon-Heathcote Estuary				
Avon River catchment	3. PJ: Pleasant Point Jetty	*A. stutchburyi*	*A. stutchburyi*	Yes
	4. T: Tern			
Heathcote River catchment	5. H: Heathcote			
	6. B: Beachville			
Rāpaki Bay				
Witch-hill/ Māori garden catchment	7. Rāpaki (R): R Beach	*A. stutchburyi* *P. australis*	*P. australis*	Yes
	8. R Rocky	*T. chilensis*	Nil	
Koukourārata/Port Levy				
'Pah' catchment	9. Koukourārata (K): K Pā	*A. stutchburyi*	*A. stutchburyi*	Yes
Puteki catchment	10. K Rocky	*T. chilensis*	Nil	

6.2.2. Sampling design

The ecological survey was carried out in the lower intertidal zone during spring tides (0.2-0.4m) in winter (June-August) and early summer (November-December) of both 2014 and 2015. These two seasonal periods were selected to investigate shellfish condition index during the pre-spawning (early summer) and dormant (winter) period, and how the CI corresponds to population structure and contaminants. The latitudinal and longitudinal coordinates for each site were recorded using a hand-held Global Position System unit (Appendix 6.1). A Ministry for Primary Industries (MPI[8]) fisheries research permit was used for the collection of study species.

Biotic population, condition index, and contaminants

For each bivalve species, the length (mm) was measured using callipers until at least 100 individuals were recorded. Sub-samples from the population survey were extracted for condition index (CI) and contaminant analysis. All extracted samples were placed in labelled containers and onto ice in a cooler for transport.

The *A. stutchburyi* and *P. australis* soft-sediment beds were surveyed using a stratified sample design, similar to previous surveys (Kainamu 2011, Adkins 2012). At each site, a grid (25 m x 10 m) was set up using wooden pegs. The grid lay parallel to the beach or waterway channel. Within each grid, bivalves from four randomly placed 0.1 m² (31.5 cm x 31.5 cm) quadrats were sampled to a depth of 10 cm. Both *A. stutchburyi* and *P. australis* are rarely found buried deeper than 10 cm below the substrate surface (Larcombe 1971, Morton and Miller 1973, Wildish 1984). The extracted material was washed with a 2.5 mm sieve to free the clams of substrate. At least fifteen clams were sampled for condition index (CI), six shellfish for trace metal analysis, and 150 g for *E. coli* analysis. Compared to the previous mid- to low-intertidal survey of *P. australis* (Mudunaivalu 2013), the current low intertidal begun at the 30-40 m mark from the shoreline at Rāpaki beach. There were no pipi beyond 50 m at Rāpaki (Mudunaivalu 2013).

Tiostrea chilensis was surveyed using a systematic design along 200 m of the rocky and large boulder shoreline. Oyster length (mm) was measured within a 1-m² quadrat, and six individuals pried from attachment for trace metal analysis. The populations were too small to extract CI or *E. coli* samples.

Samples for *E. coli* testing were delivered to Hill Laboratory Ltd within 24 hours for further analysis and the remaining samples were delivered to the University of Canterbury biology laboratory. The shellfish were measured for length (mm) and weight (g), then analysed according to the CI and trace metal procedures. Sediment was sub-sampled into samples for sediment composition and trace metal analysis. The trace metal sediment and shellfish tissue samples were freeze-dried in acid-washed vials prior to analysis.

Abiotic measurements and sediment contaminants

Replicate *in situ* water quality readings using the YSI 63 hand-held meter (salinity, temperature, and pH) and the YSI 550 hand-held meter (dissolved oxygen) were read at low tide adjacent to the shellfish grid to minimise disturbance. Sediment samples were extracted adjacent to shellfish quadrat samples, using a 15cm diameter core 10 cm depth for *E. coli* analysis, and 8.5 cm diameter core for trace metal and particle size analysis. Sediment samples were stored in labelled containers and placed on ice in a cooler to be transported to the laboratory for analysis.

6.2.3. Statistical analysis

Size class analysis

Mean densities (individual m^{-2}) and size class structure were determined by size frequency classification. This current study was guided by previous size class information for each species (Table 6.3) with the following selected for *A. stutchburyi*: recruits up to 1 year old (≥2.5mm-<10mm), small (≥10-<20 mm), mature (≥20-<30 mm), and large/harvest sized clams (≥30 mm). *Paphies australis* size classes were: juvenile (<25 mm), medium (≥25 and <40mm), mature (≥40 mm), and large/harvest sized clams (≥50 mm). *Tiostrea chilensis* size classes were: immature (<50 mm), mature adult (≥50 mm), and harvest sized clams (≥58 mm).

Table 6.3. Size classes of each species that were utilised by previous research and fishery reports as well as the current study.

Species	Size classes (mm)				Location
	Recruit	Juvenile	Mature	Harvest	
Austrovenus stutchburyi	<5	n.v.	>20	>30	Canterbury (Adkins 2012)
	>2-<19	≥19-<35	≥30	≥35	East Otago (Stewart 2008, Kainamu 2011)
	≥2.5mm-<10mm	≥10-<20 mm	≥20-<30 mm	≥30 mm	Current study (note: recruit size class included clams up to 1 year old).
Paphies australis	no value	<25	≥40	*≥50	Auckland, Canterbury. *An estimated size (Hooker and Creese 1996, Mudunaivalu 2013, MPI 2014). The current study included the same size classes in addition to a medium size class (≥25 and <40mm).
Tiostrea chilensis	no value	<50	**≥50	***>58	Foveaux Strait; **Female maturity, ***Commercial landing size and the legal harvest size of the South-East fisheries (Ministry of Fisheries 2009, Fu 2013, MPI 2016). The current study included the same size classes.

General statistical analysis

All data were checked for normality using Statistica™ Version 13 as described in Section 2.5. When the assumptions of normality were not met and transformation did not improve this, a non-parametric analysis was used (such as dredge oyster density data). The abiotic data, population biology variables, and contaminants were compared spatially and temporally using general linear models, followed by a post-hoc Tukey homogenous test where there was significance (α=0.05).

Condition index data

The *P. australis* CI data met normality, while the *A. stutchburyi* CI consisted of outliers (outside the 95% regression bands at ±2.5 SD). Once these outliers were removed (17 out of 513) and CI data transformed by log 10, normality was met for all sites. The homogeneity of slopes showed size (length and soft tissue) significantly influenced both *A. stutchburyi* and *P. australis* CI, thus separate slopes was used to spatially and temporally compare CI.

Contaminant analyses

The sediment contaminant data were compared using Factorial ANOVA to test for the influence of site, season, year, and the interaction of these variables on contaminant concentrations. Since the *E. coli* data contained only one replicate per site each sampling period, Kruskal Wallis analysis was used to compare across sites, while season and year compared using the Mann-Whitney U test. Before any comparison between tissue trace metal concentrations (ppm dry weight) across sites, it was necessary to check if the size influences the accumulated tissue concentration which could compromise any comparisons (Peake et al. 2006), as explained in the general methodology section (Chapter 2). Both the tissue metal concentrations of *A. stutchburyi* and *P. australis* met normality. The ANCOVA assumptions were violated by the interaction of shellfish size (length or tissue weight) with the trace metal concentration, so the separate slopes analysis was used to analyse these across sites, season, and year. *Tiostrea chilensis* data did not meet normality, thus the Mann-Whitney U test was used. Also, *A. stutchburyi* tissue was sampled for *E. coli* at all soft-sediment sites, except at Rāpaki due to low population density. Instead, *P. australis* was sampled.

Correlation analyses

Since many of the variables did not meet the normality assumptions for the correlation analysis, the Spearman rank test was used. Correlation first tested the influence of salinity, total rainfall, and catchment land use on *A. stutchburyi* tissue and sediment contaminant (*E. coli* and metal) concentrations. The second correlation analysis focussed on the associations, and influence, of *A. stutchburyi* tissue and sediment contaminant and abiotic variables (DO: dissolved oxygen, temperature, salinity, pH) to *A. stutchburyi* tissue and sediment contaminant. Sediment *E. coli* concentrations were not included within the correlation analysis because they were below the detection limit. The Benjamini-Hochberg procedure was used to control for False Discovery Rates (FDR, Chapter 2) and a FDR of 5% was applied in this study as used in past studies (Stark and Fowles 2006, Whitney et al. 2010).

6.3. Results

6.3.1. Landscape condition and abiotic measures

For clarity, the sites with lower saline conditions are termed low salinity while those with higher saline conditions are termed marine. Of the ten sediment sites, eight were clam beds (SCR, SCM, PJ, Tern, Heathcote, Beachville, Rāpaki beach and Koukourārata pā) and two were rocky shore (Rāpaki rocky and Koukourārata rocky; Table 6.2).

Landscape condition (LDI and impervious surface area)

The Land Development Intensity (LDI) range was 3.56-7.42, highest at the urban Avon River catchment and lowest at the more rural Witch Hill-Māori Gardens catchment of Rāpaki Bay (Table 6.4). The Avon River catchment predominantly comprised of impervious surface (91.0%) compared to the rural catchments of Witch Hill-Māori Gardens (1.0%), Saltwater Creek (0.5%) and Puteki of Koukourārata (0.0%). These latter catchments were predominantly comprised of low producing grassland (62.5%) at Witch Hill-Māori Gardens and high-producing exotic grassland at Saltwater Creek (70.5%) and Puteki (97.8%; Figure 6.2).

Water quality

Across the ten sites, low tide salinity ranged between 6.0-33.6 ppt, water temperature between 4.32-21.30˚C, pH between 6.6-8.4, and dissolved oxygen (DO) between 6.3-14.70 mg/L (Table 6.4). Across the three catchments (Saltwater Creek, Avon-River and Heathcote-River), water quality metrics were influenced by site, season and year (Appendix 6.2). Salinity was higher at marine sites (Tern and Beachville) compared to low salinity sites SCR ($F(5,48)=540.46$, $p<0.0001$). Water temperature was significantly warmer at Beachville and cooler at PJ ($F(5,48)=86.33$, $p<0.0001$). The pH was lower at SCM and higher at Beachville, Heathcote, and Tern ($F(5,48)=126.33$, $p<0.0001$). The DO was lower at Heathcote, and higher at SCR, SCM, and Tern ($F(5,48)=34.87$, $p<0.0001$). In addition, water was warmer and more saline, in summer than in winter ($p<0.0001$) and in 2015 compared to 2014 ($p<0.0001$).

Across the high salinity sites (Rāpaki Beach, Koukourārata pā, Tern, Beachville, and SCM), salinity was highest at Rāpaki Beach and Koukourārata pā and lowest at SCM ($F(4,39)=800.72$, $p<0.0001$). Water temperature and DO were significantly higher at Koukourārata pā than other sites ($F(4,39)=182.5$, $p<0.0001$; $F(4,39)=26.93$, $p<0.0001$). The pH was similarly higher at Rāpaki, Beachville and Tern ($F(4,39)=298.5$, $p<0.0001$). In addition, water was warmer and more saline in summer than in winter ($p<0.001$), and in 2015 compared to 2014 ($p<0.0001$).

At the Rāpaki and Koukourārata rocky shore sites, the water quality metrics were significantly influenced by season and site. Temperatures were lower at Rāpaki in winter 2015 ad highest at Rāpaki in summer 2015 ($F(1,15)=138.41$, $p<0.0001$), while salinity was lower at Rāpaki in winter 2014 ($F(1,15)=6.57$, $p<0.05$). Conversely, pH (7.5-8.07) was lower at Koukourārata in summer 2015 compared to other sampling periods ($F(1,15)=15.51$, $p<0.01$) and DO (7.02-16.93 mg/L) was lower at Rāpaki in summer 2014 but higher at Koukourārata in summer 2014 ($F(1,15)=117.90$, $p<0.0001$).

Sediment composition

Sediment size composition was variable across clam bed sites (Figure 6.2 and Appendix 6.2). The SCR, SCM and Koukourārata pā sites were predominantly composed of silt (<63 µm), very fine (>63 µm), and fine sand (>125 µm; Figure 6.3). The Avon-Heathcote Estuary sites varied between predominantly fine sand and very fine sand, while Rāpaki Beach varied between medium, fine, and very fine sand.

Across the sites, silt and very fine sand composition were higher at SCR and SCM ($F(5,50)=48.52$, $p<0.0001$ and $F(5,50)=4.88$, $p<0.01$, respectively). Fine sand was higher at Beachville and lower at SCR (DF=5, F=27.83, $p<0.0001$). The percent Pore Water (PW) and Total Volatile Solids (TVS) of sediment samples were both significantly higher at Tern (Figure 6.3; $F(5,50)=5.84$, $p<0.001$; $F(5,50)=14.71$, $p<0.0001$; no table). Compared to other high salinity sites, silt was higher at both SCM and Koukourārata ($F(4,40)=17.10$, $p<0.0001$), very fine grain was higher at Koukourārata ($F(4,40)=26.2$, $p<0.0001$), medium sand (>250 µm) was higher at Rāpaki, and coarse grain (>500 µm) was higher at SCM and Rāpaki ($F(4,40)=4.9$, $p<0.01$).

Across seasons, the occurrence of both very fine and silt particle sizes were significantly higher in winter than summer ($F(1,40)=26.2$, $p<0.0001$; $F(1,40)=5.3$, $p<0.05$), but very coarse, fine grain, percent PW and TVS were higher in summer ($F(1,40)=4.8$, $p<0.05$; $F(1,40)=5.06$, $p<0.001$; $F(1,40)=5.93$, $p<0.001$; $F(1,40)=3.88$, $p<0.01$, respectively; Appendix 6.2). Lastly, the occurrence of medium sands was higher in 2015 and very fine sand in 2014 ($F(1,40)=34.1$, $p<0.0001$; $F(1,40)=26.2$, $p<0.01$).

Between the rocky sites, sediment composition varied by site and season (Figure 6.2-6.3; Statistics in Appendix 6.2). Rāpaki was characterised by very fine sands ($F(1, 19)=5.65$, $p<0.05$) and Koukourārata rocky by medium sands ($F(1, 19)=7.84$, $p<0.05$). The occurrence of medium sand was higher in winter than in summer ($F(1,19)=11.5$, $p<0.01$) and the percent TVS and PW were higher in summer than in winter ($F(1,19)=11.1$, $p<0.01$; $F(1,19)=4.4$, $p<0.05$).

Table 6.4. Study catchments and sites, land development intensity (LDI), impervious surface area (%), and low tide water readings for winter (W) and summer (S).

Catchment	Sites	LDI (impervious surface %)	Sampling period	Salinity (ppt)	Temperature (℃)	DO (mg/L)	pH
Replicate sites (low and high salinity)							
Saltwater Creek	SCR (Saltwater Creek River)	4.37 (0.46%)	W 16.06.2014	7.53±0.03	7.30±<0.01	11.49±0.05	7.35±0.01
			S 03.12.2014	6.70±0.21	12.08±0.03	11.83±0.03	6.62±0.13
			W 15.06.2015	6.50±0.21	10.08±0.23	9.88±0.32	7.20±0.01
			S 23.11.2015	9.50±0.15	13.92±0.03	9.42±0.06	7.04±0.30
	SCM (Saltwater Creek Marine)		W 17.06.2014	9.50±0.15	7.22±0.02	11.53±<0.01	7.21±0.05
			S 04.12.2014	7.97±0.41	13.40±0.06	13.40±0.06	6.77±0.12
			W 16.06.2015	11.73±0.23	9.35±0.03	9.74±0.03	7.50±0.01
			S 24.11.2015	15.80±0.45	14.58±0.04	8.79±0.21	No value
Avon River	PJ (Pleasant Point Jetty)	7.42 (90.96%)	W 18.06.2014	6.03±0.65	7.08±0.20	11.62±0.24	7.86±0.04
			S 06.11.2014	6.90±0.35	11.40±<0.01	6.25±0.10	6.65±0.26
			W 13.07.2015	8.87±0.37	5.22±0.03	11.45±0.27	7.51±0.13
			S 01.12.2015	23.53±1.52	18.78±0.27	10.20±0.15	7.95±0.05
	Tern		W 19.06.2014	22.80±<0.01	4.32±0.02	13.00±0.01	7.76±0.04
			S 05.11.2014	28.17±0.03	12.93±0.11	8.86±0.27	8.53±0.14
			W 17.07.2015	30.77±1.39	9.12±0.29	12.10±0.21	8.06±0.05
			S 26.11.2015	32.30±0.61	21.30±0.23	11.82±0.71	8.09±0.11
Heathcote River	Heathcote	7.38 (85.34%)	W 09.08.2014	28.63±0.37	10.18±0.08	10.82±0.15	8.07±0.01
			S 08.11.2014	15.20±0.80	16.37±0.36	6.57±0.11	7.35±0.16
			W 14.07.2015	10.03±0.13	6.83±0.15	11.81±0.18	7.82±0.02
			S 08.11.2015	18.57±0.26	19.55±0.58	8.59±0.25	7.60±0.21
	Beachville		W 12.08.2014	25.17±0.15	9.30±<0.01	10.21±0.01	8.13±0.02
			S 03.11.2014	18.40±1.51	12.58±0.02	7.08±0.15	8.05±0.02
			W 15.06.2015	30.33±0.58	8.30±0.15	12.64±0.03	7.98±0.03
			S 25.11.2015	31.97±0.13	17.20±0.28	9.93±0.21	8.01±0.02
Additional mātaitai shellfish sites (high-salinity)							
Witch-hill/Māori garden	Rāpaki Beach	3.56 (1.01%)	W 16.07.2014	27.50±0.36	10.08±0.02	11.46±0.21	7.99±0.05
			S 07.11.2014	30.17±0.03	13.70±<0.01	7.02±0.03	7.71±0.24
			W 03.08.2015	32.24±0.07	6.57±0.06	12.72±0.12	8.10±0.01
			S 14.12.2015	32.85±0.04	14.57±0.27	10.99±0.01	8.44±0.04
	Rāpaki Rocky		W 16.07.2014	27.50±0.36	10.08±0.02	11.46±0.21	7.99±0.05
			S 07.11.2014	30.17±0.03	13.70±<0.01	7.02±0.03	7.71±0.24
			W 03.08.2015	31.60±0.10	6.67±0.02	12.43±0.20	8.07±0.01
			S 14.12.2015	32.54±0.22	19.37±0.39	11.70±0.37	7.50±0.44
Pā	Koukourārata Pā	3.91 (1.10%)	W 17.07.2014	28.60±0.21	8.78±0.02	10.71±0.01	7.92±0.01
			S 05.12.2014	30.10±0.15	15.00±<0.01	14.70±<0.01	7.81±0.02
			W 07.08.2015	28.90±2.11	9.00±0.15	11.12±0.28	7.98±0.02
			S 05.12.2015	33.60±0.10	19.38±0.04	9.75±0.09	No value
Puteki	Koukourārata Rocky	5.00 (0.00%)	W 15.07.2014	29.63±0.07	9.72±0.15	12.24±0.32	7.98±0.03
			S 09.12.2014	30.23±0.17	17.23±0.03	16.93±0.05	8.02±0.05
			W 18.06.2015	33.30±0.10	10.13±0.06	10.76±0.34	8.03±0.01
			S 09.12.2015	35.00±1.81	19.00±0.34	11.12±0.44	No value

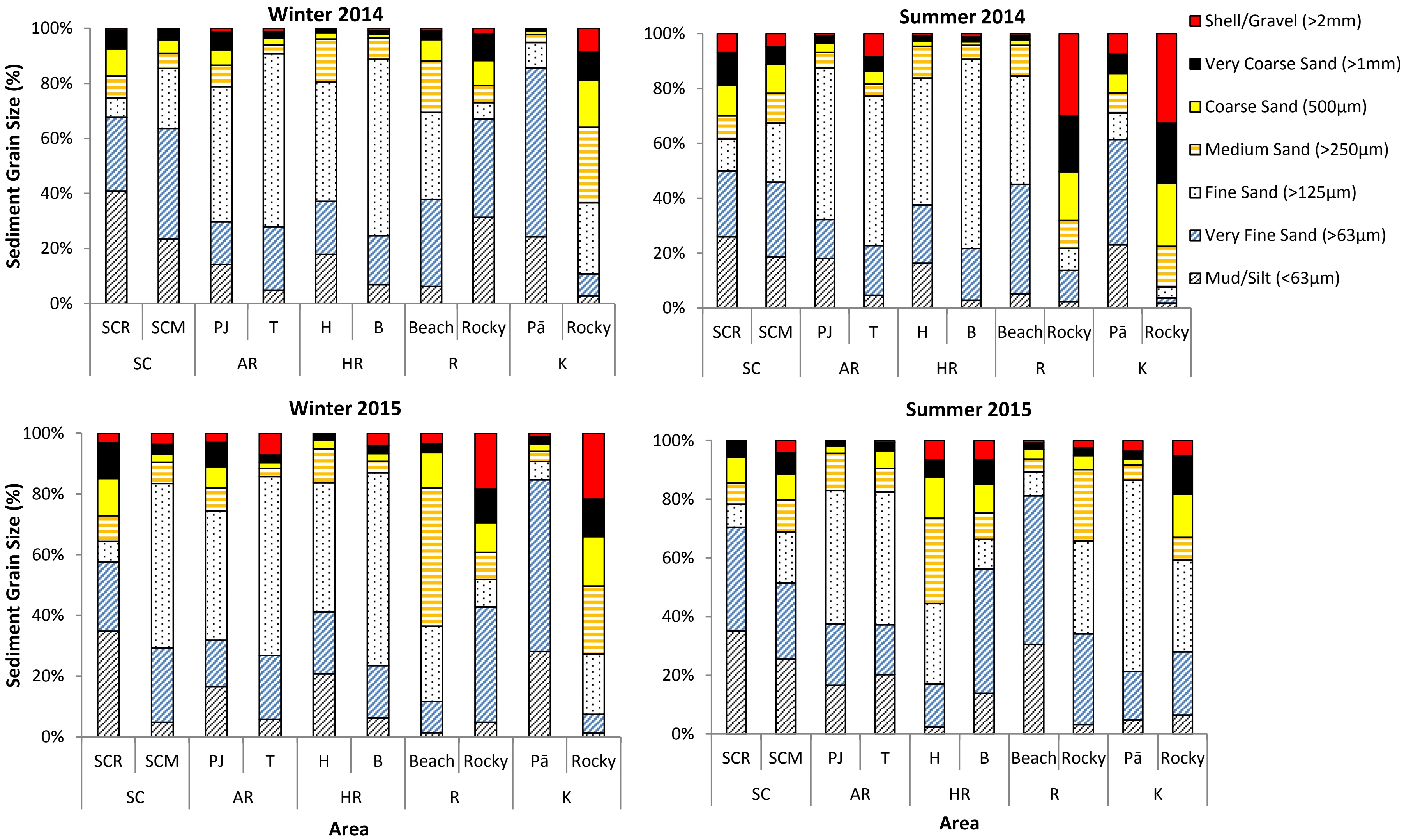


Figure 6.2. Percent sediment grain size composition (n=3 all sites, and n=4 at Rāpaki rocky). Area and site names are provided in Table 6.2.

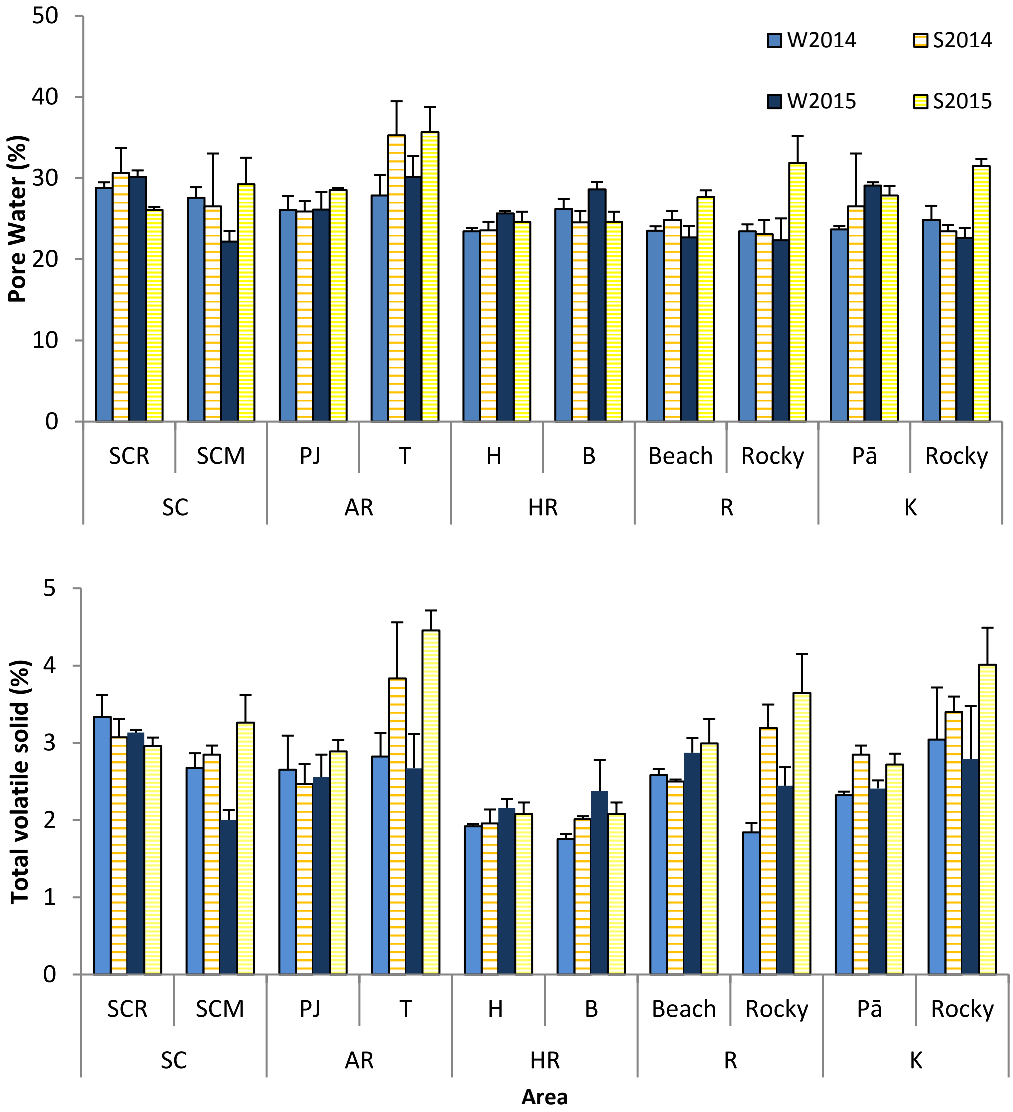


Figure 6.3. Percent pore water and total volatile solid (±S.E.) for each site and season. Area and site names are provided in Table 6.2.

6.3.2. *Austrovenus stutchburyi* population biology

Cockle density, length, and population distribution

Cockle density (7-256 clams m^{-2}) was influenced by salinity, site, and site by year interaction (Figures 6.4-6.7 and Appendix 6.3). Compared across catchments (Saltwater Creek, Avon-River, and Heathcote River) cockles were more abundant at two marine sites (SCM and Tern) and less abundant at a lower saline site (PJ) ($F(5,244)=9.84$, $p<0.0001$). Compared across all eight sites, cockle density was higher at Tern and SCM and significantly lower at Rāpaki beach ($F(7,288)=9.67$, $p<0.0001$). The interaction with year, showed higher densities at SCM in 2015, followed by Heathcote 2015, and lowest at Rāpaki in 2014 ($F(7,288)=3.95$, $p<0.001$).

The length of cockles was influenced by site, year, site by year and site by season interaction. Across sites, Koukourārata pā had larger clams and Tern had smaller ($F(7,280)=11.09$, $p<0.0001$). Across year, clams were significantly smaller in 2015 than 2014 ($F(1,280)=45.34$, $p<0.0001$). The interaction with temporal variables, illustrated the larger clams at Koukourārata pā in 2014 and smaller in 2015, especially Tern ($F(7,280)=3.31$, $p<0.01$); while seasonal variability showed no uniform pattern across sites ($F(7,280)=2.21$, $p<0.05$).

The cockle populations of SCR, SCM, and PJ, exhibited skewed unimodal distributions over time (G_1=-1.91 to 1.76) and were predominantly composed of medium and large clams (Appendix 6.3) The Tern clam population varied from bimodal, to unimodal, and multimodal distributions, i.e. Tern (7 mm, 29 mm, 31 mm). Heathcote was predominantly unimodal and negatively skewed until 2015, when it became multimodal (8 mm, 12 mm, and 24 mm). Beachville exhibited multimodal over time (11mm, 27 mm, and 30 mm). Neither Koukourārata nor Rāpaki sites had consistent population structure patterns, varying between immature and large clams.

Juvenile (>2-<19 mm) density was low at most sites. The sites of SCR, SCM, PJ, Rāpaki, and Koukourārata pā sites had predominantly larger clam distributions with low juvenile recruitment (0.0-1.0 clams m^{-2}) in 2014, which was higher in 2015 (0.6-20.0 clams m^{-2}; Appendix 6.3). The juvenile recruitment at these sites and that of Beachville (1.8-11.3 clams m^{-2}) were significantly lower than Heathcote (6.4-48.3 clams m^{-2}) and Tern (18.3-28.0 clams m^{-2}; $F(7,86)=24.74$, $p<0.0001$). Tern and Beachville sites had predominantly smaller clams and recruited each season, while Heathcote, had predominantly larger clams. The latter also recruited each season. Heathcote had higher recruitment in summer 2015. Recruitment of clams was lower in 2014 than 2015 ($F(12,86)=33.38$, $p<0.0001$), and without seasonal effect.

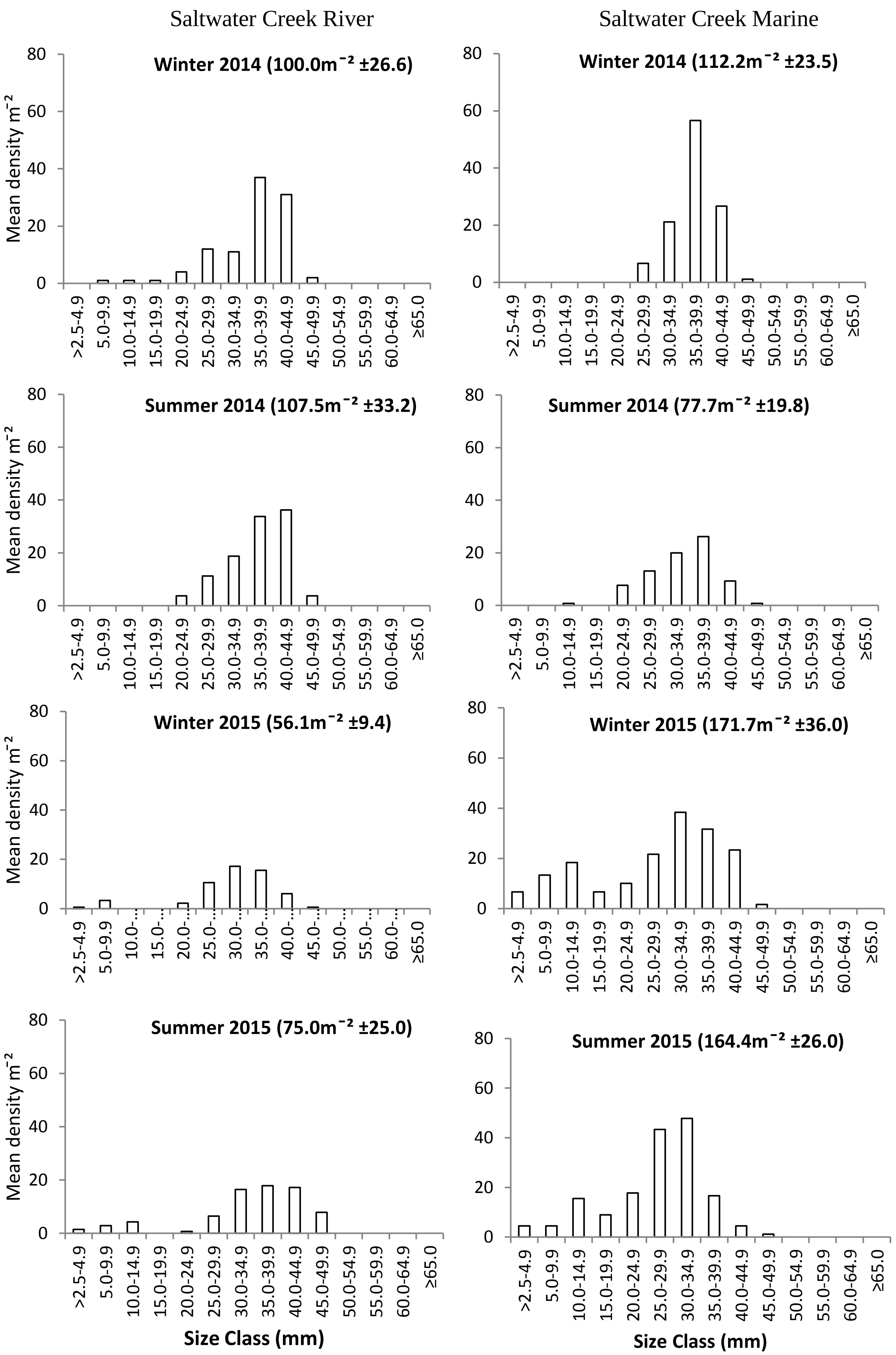


Figure 6.4. Population size structure and the site mean density (individuals per m² ±S.E.) of *A.stutchburyi* for each season at Saltwater Creek Estuary catchment.

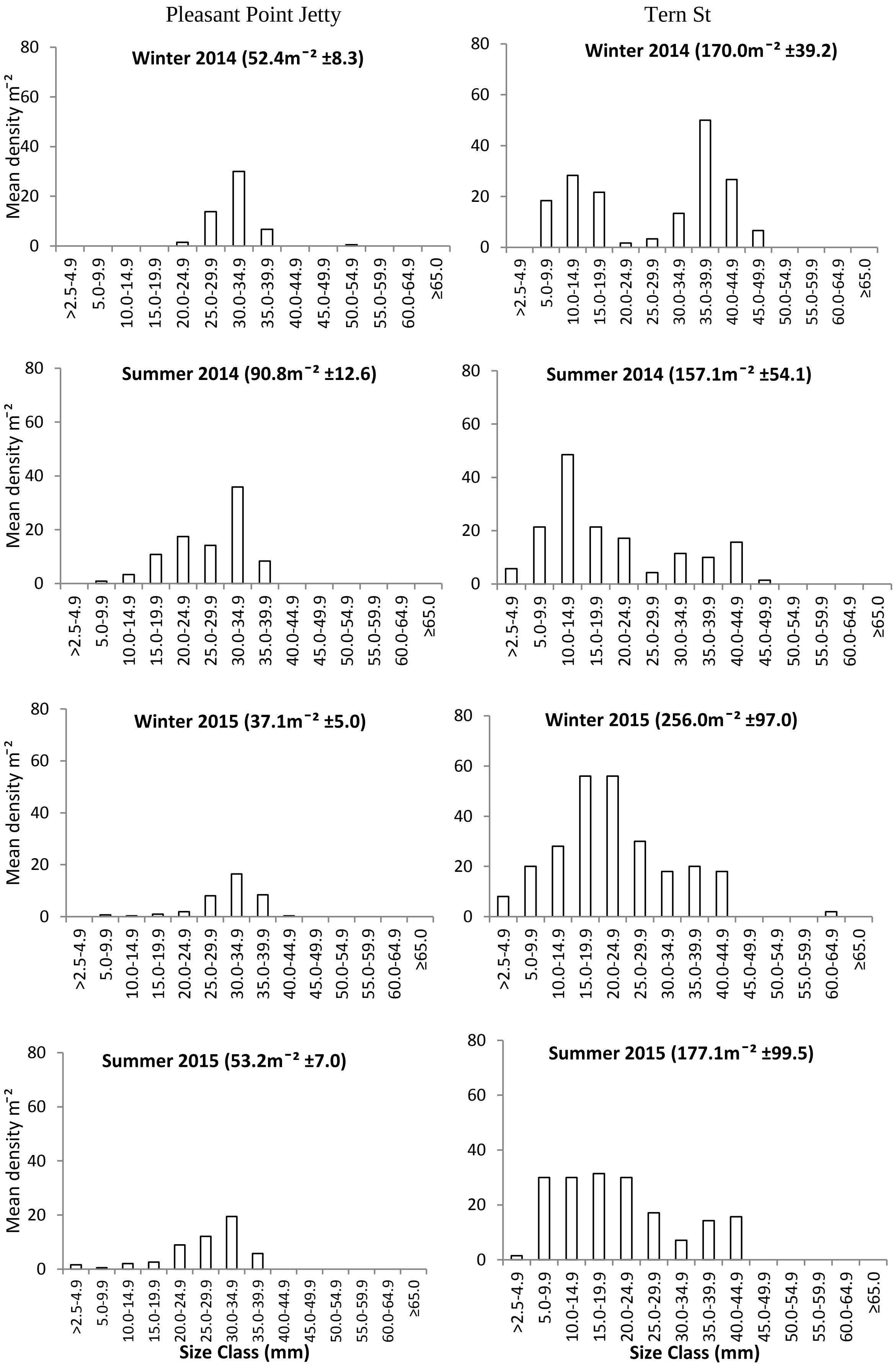


Figure 6.5. Population size structure and the site mean density (individuals per m² ±S.E.) of *A. stutchburyi* for each season in the Avon River catchment.

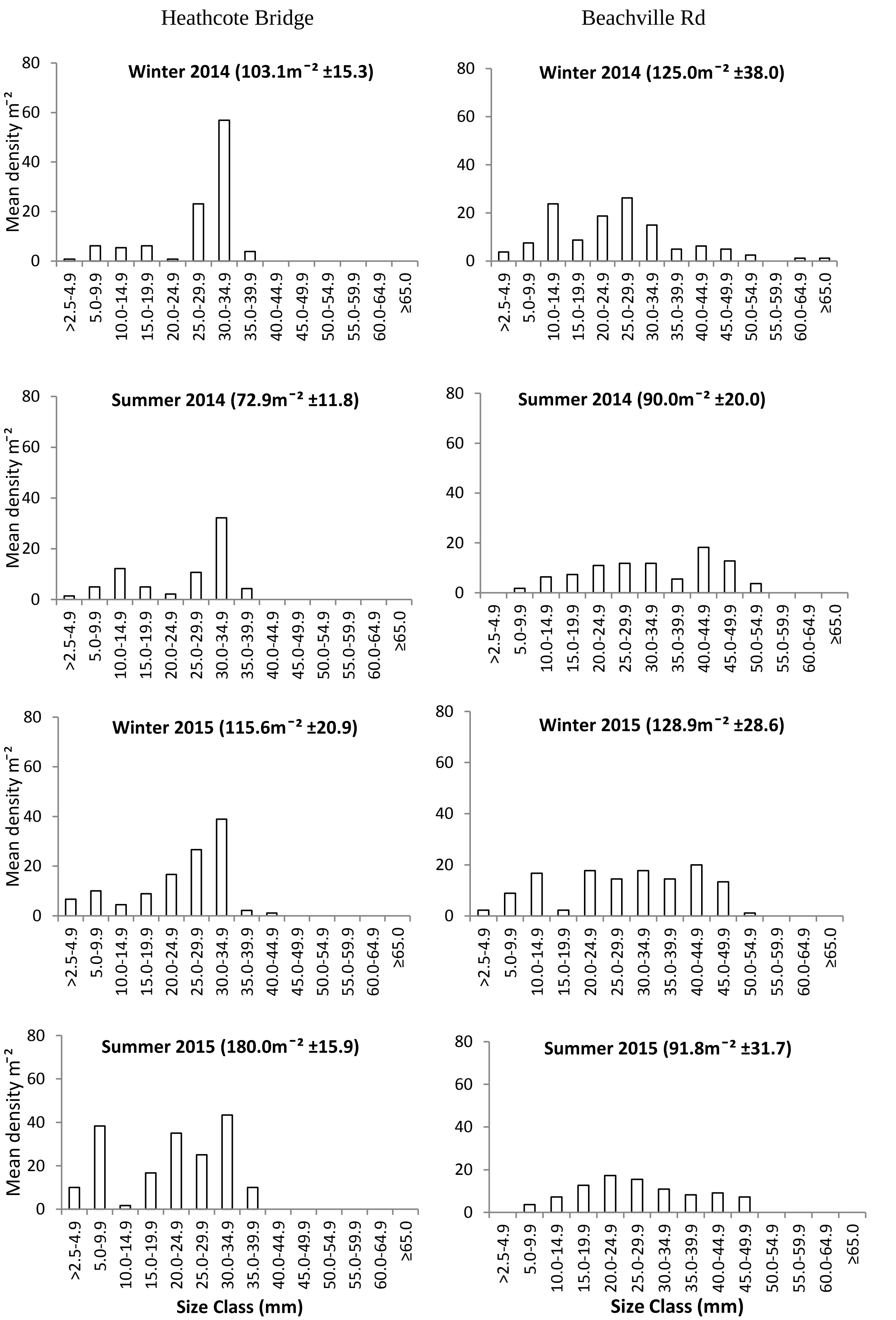


Figure 6.6. Population size structure and the site mean density (individuals per m² ±S.E.) of *A. stutchburyi* for each season in the Heathcote River catchment.

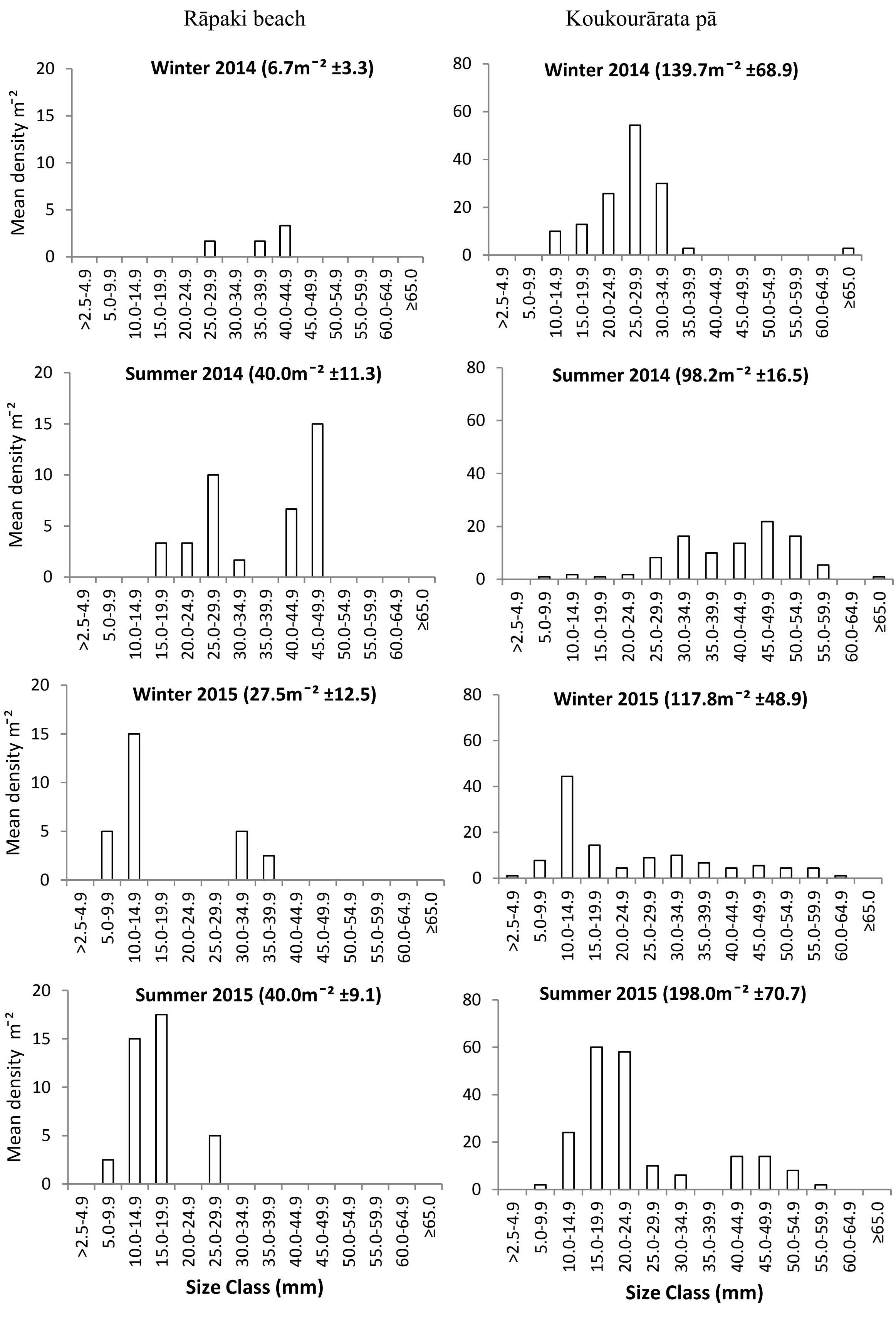


Figure 6.7. Population size structure and the site mean density (individuals per m² ±S.E.) of *A. stutchburyi* for each season at Rāpaki beach (Witch Hill-Māori catchment) and Koukourārata pā ('Pah' catchment). Note: The Rāpaki beach y-axis is different to the others.

Cockle condition index

The mean cockle length (14-39 mm) was not a major determinant of condition index (CI: 40-92) with few (8/32) significant relationships (Figure 6.8, Table 6.5). The relationship between length and CI in summer 2015 was strong at SCR (n=12, $r^2 \geq 0.6$, $p<0.01$), and moderate at SCR and SCM in winter 2014 (n=18, $r^2 \geq 0.4$, $p<0.001$ and n=15, $r^2 \geq 0.4$, $p<0.01$, respectively), Heathcote in summer 2014 (n=12, $r^2<0.4$, $p<0.05$), and Koukourārata pā in winter 2015 (n=17, $r^2 \geq 0.4$, $p<0.01$). Three of the relationships were weak, which was SCM and Beachville in summer 2014 (n=12, $r^2<0.4$, $p<0.05$ and n=15, $r^2<0.4$, $p<0.05$, respectively), and PJ in winter 2015 (n=15, $r^2<0.3$, $p<0.05$). Two of the CI and length relationships were positive in summer (SCR and Beachville) and two were negative in winter (SCR and SCM). During summer, both SCM and Heathcote CI were negatively related to length. The CI was significantly different across sites, but not across season or year. The cockle CI was highest at both Koukourārata pā and Tern, and lowest at both Heathcote and PJ ($F(7,107)=22.4$, $p<0.0001$).

Correlation analyses of the cockle indices and abiotic variables

The cockle biological indices (recruitment density, mean density, max shell length, mean shell length, and CI: condition index) correlated with the landscape condition and abiotic variables (Appendix 6.7). The Landscape Development Intensity (LDI) index and impervious surface were positively correlated with recruitment density (R=0.40, $p<0.01$; R=0.34, $p<0.01$, respectively), and negatively correlated with CI (R=-0.28, $p<0.01$; R=-0.24, $p<0.05$, respectively). The impervious surface also negatively correlated with mean shell length (R=-0.40, $p<0.0001$). Further to this, recruitment density was also positively correlated with mean density (R=0.48, $p<0.0001$, no table).

Very few correlations were significantly correlated between water quality readings and the population biological indices. Temperature, pH, and DO were positively correlated with recruitment density (R=0.42, $p<0.0001$; R=0.36, $p<0.001$; F=0.23, $p<0.05$, respectively), but negatively correlated with mean shell length (R=-0.50, $p<0.0001$; R=-0.32, $p<0.01$; R=-0.28, $p<0.01$, respectively). Also, the CI was positively correlated with salinity, temperature and pH (R=0.42, $p<0.0001$; R=0.50, $p<0.0001$; R=0.25, respectively).

Sediment size composition was negatively associated with population indices (Appendix 6.7). Recruit clam density negatively correlated with coarse sand (>500 µm; R=-0.28, $p<0.01$) and silt (<63 µm; R=-0.23, $p<0.05$) but positively correlated with fine sand (>125 µm; R=0.27, $p<0.01$). Mean shell length also negatively correlated with coarse sand (R=-0.34, $p<0.001$). Mean density negatively correlated with medium sand (>250 µm; R=-0.46, $p<0.0001$), this grain size also negatively correlated with mean shell length (R=-0.42, $p<0.0001$), and CI (R=-0.24, $p<0.05$). The CI was also negatively correlated with fine sand (R=0.27, $p<0.01$) and percent total volatile solids (R=-0.36, $p<0.001$), and positively correlated with gravel/shell (R=0.26, p<0.01) and percent pore water (R=0.30, p<0.01). Maximum shell length was positively correlated with both silt and very coarse sand (>1mm; R=0.36, p<0.01; R=0.27. p<0.01, respectively).

Table 6.5. The regression relationship between the log-transformed *A. stutchburyi* condition index (CI) and length (mm). The sample size (n), regression value (r^2), and p-value are given, with significant values in bold. Site names are provided in Table 6.2.

	Winter 2014			Summer 2014			Winter 2015			Summer 2015		
Sites	n	r^2	p-value	n	r^2	p-value	n	r^2	p-value	n	r^2	p-value
SCR	18	0.56	**<0.001**	16	0.17	0.11	16	0.23	0.06	12	0.64	**<0.01**
SCM	15	0.44	**<0.01**	12	0.37	**<0.05**	16	0.03	0.53	17	<0.01	0.99
PJ	15	0.02	0.63	16	0.19	0.11	15	0.29	**<0.05**	18	0.01	0.65
T	20	0.03	0.47	17	0.17	0.10	16	<0.01	0.99	18	1.00	**No value**
H	14	0.07	0.36	17	0.49	**<0.01**	14	0.03	0.58	18	0.01	0.75
B	10	0.13	0.30	15	0.26	**<0.05**	16	0.21	0.08	16	0.02	0.62
R	19	0.14	0.11	20	0.08	0.22	7	0.05	0.62	11	0.29	0.09
K	17	0.15	0.13	13	0.05	0.46	15	0.02	0.60	17	0.41	**<0.01**

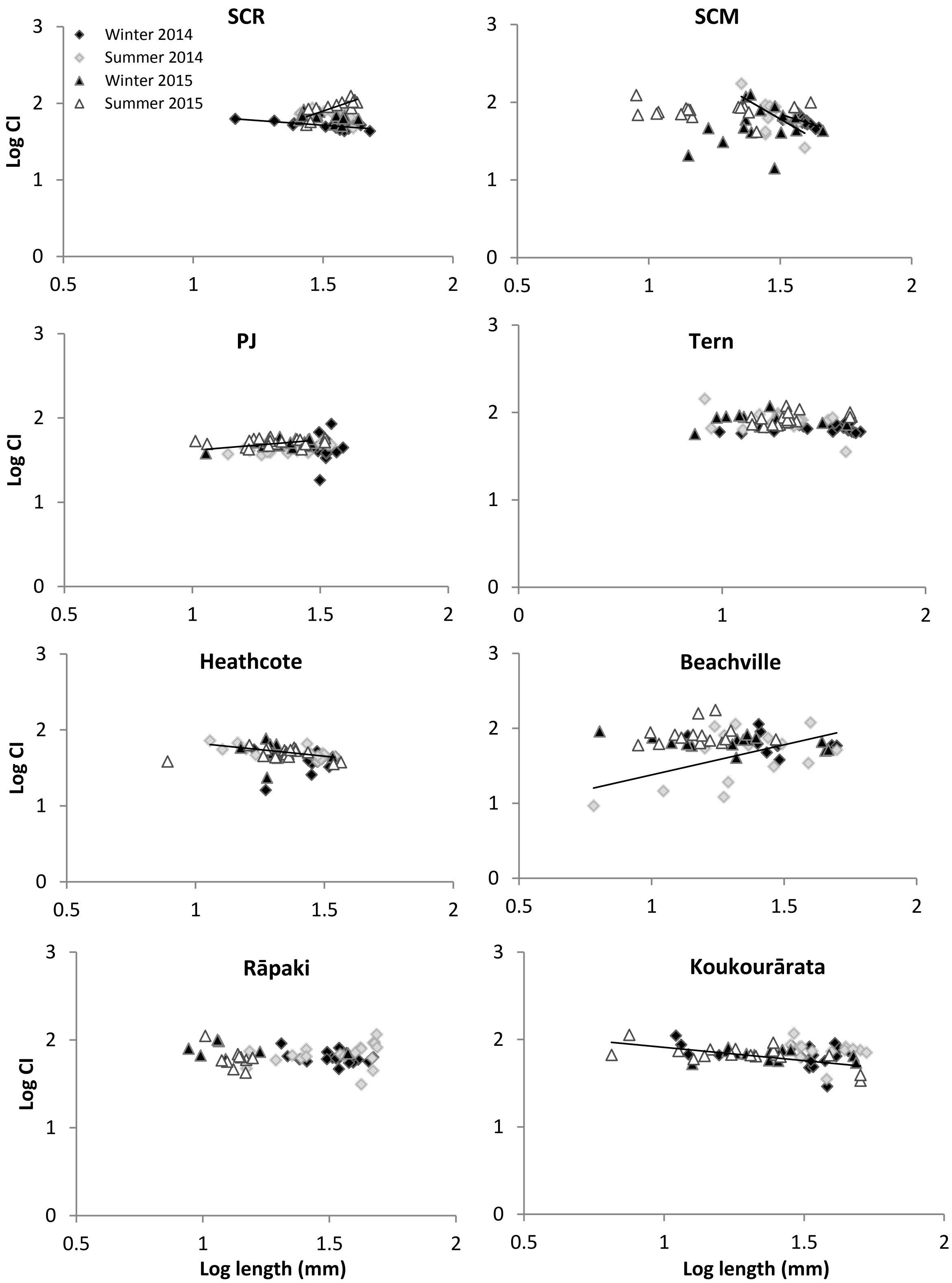


Figure 6.8. The relationship between *A. stutchburyi* condition index (CI) and length (mm). The data were log-transformed. Note x-axis begins at 0.5 mm. The regression lines are shown for significant results, and the sample size and regression coefficient values are provided in Table 6.5. Site names are provided in Table 6.2.

6.3.3. *Paphies australis* and *Tiostrea chilensis* population biology

P. australis density and population structure, length and condition index

The Rāpaki beach pipi density (178-393 clams m^{-2}) and population structure exhibited an abundance of large clams (Figure 6.9, Appendix 6.4). Although the mean density range increased from 178±58 clams m^{-2} to 393±101 clams m^{-2}, this was associated with large variability (S.E.). Therefore, density did not vary over time ($p>0.01$). The population structure exhibited negative and highly skewed unimodal distributions, dominant in mature medium sized clams (47-49 mm), except winter 2015, when harvestable sized pipi (50 mm) were dominant. Juvenile recruitment (13.3-47.5 clams m^{-2}) was higher during winter, especially winter 2015, coinciding with significantly higher mean shell length in summer ($F(1,15)=8.96$, $p<0.01$).

The mean condition index (CI: 103-122) and the associated shell length (36-46 mm) were influenced by season (Figure 6.10, Appendix 6.4). The CI was higher in summer ($F(1,62)=5.66$, $p<0.05$). In winter 2014, the regression between length and CI significantly was negative ($n=17$, $r^2=0.81$, $p<0.001$, not shown), and was not significant any other times. Therefore, length was not a major determinant of condition index.

T. chilensis density, population structure and length

Tiostrea chilensis density was sparse (2.5-4.5 clams m^{-2}) and small oysters (27-36 mm) dominated both Rāpaki and Koukourārata populations structures (Figure 6.11, Appendix 6.5). The mean density range was 2.8-4.5 clams m^{-2} at Rāpaki and 2.5-4.0 clams m^{-2} at Koukourārata. Both sites were dominated by juvenile oysters over time (<50 mm), and harvestable sized oysters (≥58 mm) were only observed during winter 2014, but were low in density at Koukourārata (0.05 clams m^{-2}). There was no significant variation in density or length across sites or over time ($p>0.05$).

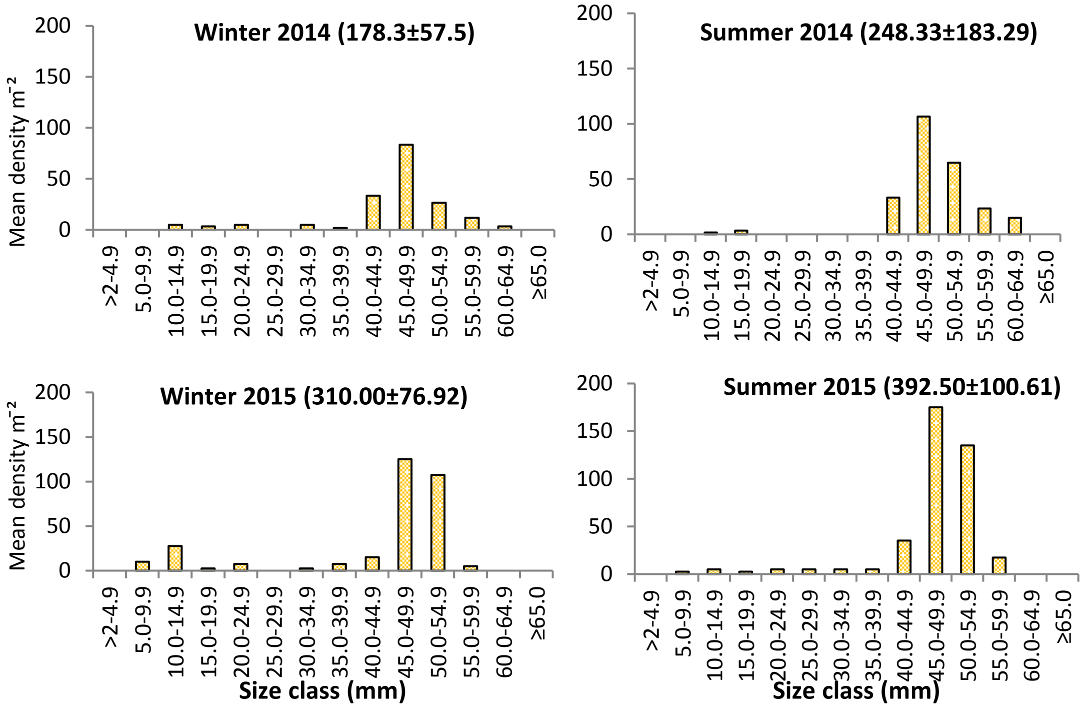


Figure 6.9. Population size structure and the site mean density (individuals per m² ±S.E.) of *P. australis* for each season at Rāpaki beach. Size classes are: juvenile (<25mm), mature (≥40 mm), and harvest (≥50 mm).

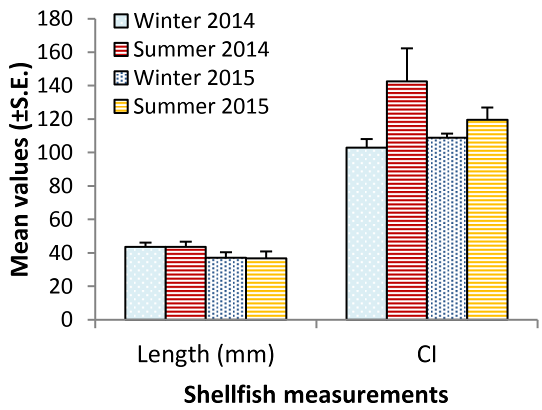


Figure 6.10. The mean length (mm ±SE) and condition index (CI ±SE) of *P. australis* for each season at Rāpaki beach.

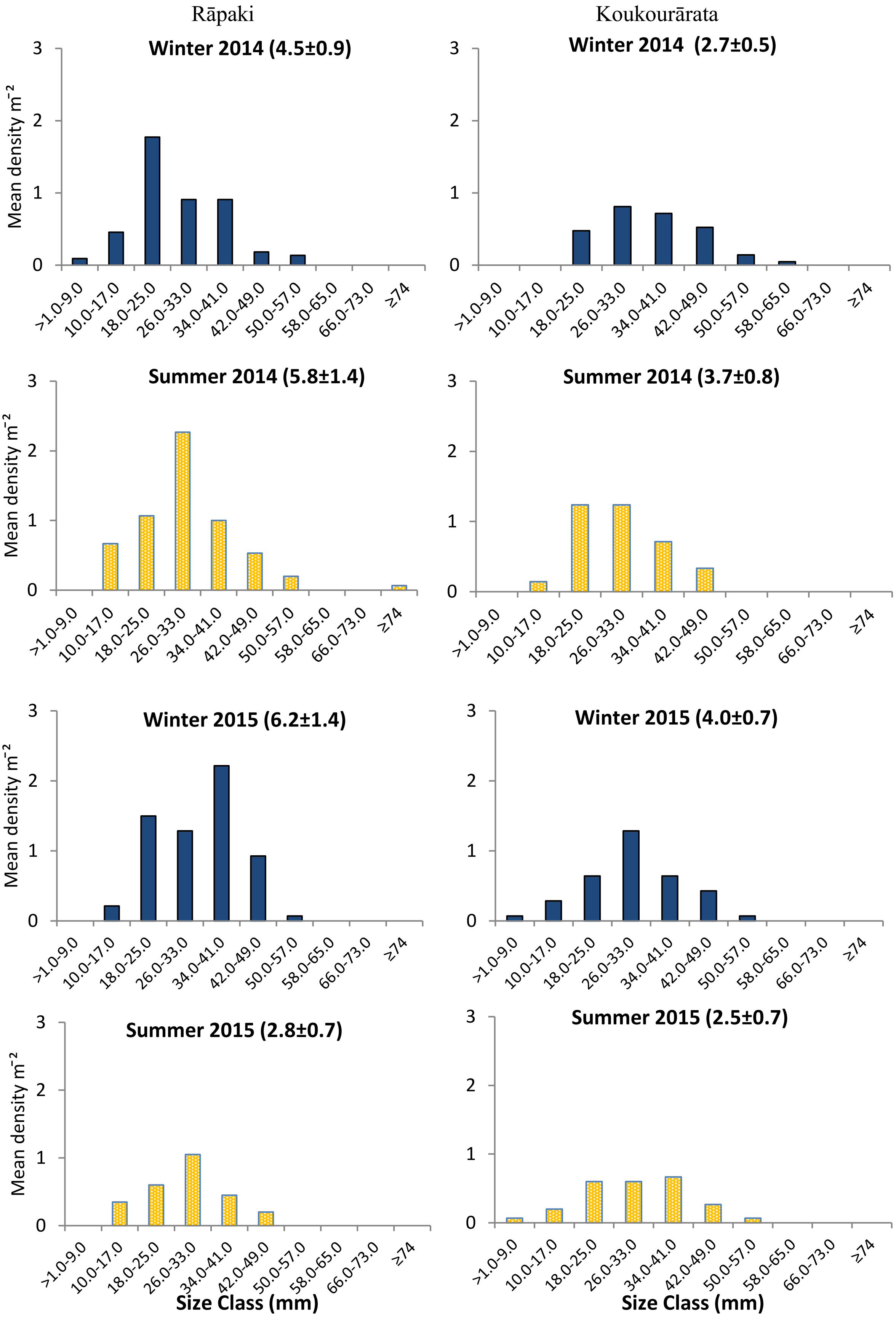


Figure 6.11. The population size structure and the site mean density (individuals per m² ±S.E.) of *T. chilensis* for each season at Rāpaki and Koukourārata rocky sites.

6.3.4. Trace metal analysis

Sediment analysis

Sediment contaminant concentration (ppm dry weight) were analysed across ten sites (Figure 6.12). These included the soft sediment samples from eight clam beds (SCR and SCM: Saltwater Creek River and Marine, PJ: Pleasant Point Jetty, Tern, Heathcote, Beachville, Rāpaki beach, Koukourārata pā), and sediment within the rocky shores (Rāpaki rocky and Koukourārata rocky). The mercury results were variable and problematic, and excluded from the final analyses. The recovery values of the Certified Reference Material (CRM) and limit of detection are provided (Appendix 2.5).

The sediment contaminant concentration range for the combined samples is as follows (Figure 6.12). Sediment concentrations of As (2.41-9.00 ppm), Cd (0.02-0.11 ppm), Co (3.91-12.65 ppm), Cr (7.57-33.52 ppm), Cu (2.81-12.27 ppm), Mn (128.19-429.29 ppm), Ni (4.85-13.73 ppm), Pb (6.89-20.97 ppm), and Zn (28.13-115.39 ppm). The Metal Pollution Index (MPI_8) range was 5.67-12.18 ppm.

Sediment contaminant concentrations were elevated in 2014 compared to 2015 (Appendix 6.6) for As, Co, Cr, Cu, Mn, Ni, Pb, and Zn ($F(1,84)=6.25$, $p<0.01$; $F(1,84)=10.11$, $p<0.01$; $F(1,84)=18.73$, $p<0.0001$; $F(1,84)=21.8$, $p<0.0001$; $F(1,84)=16.53$, $p<0.001$; $F(1,84)=16.53$, $p<0.001$; $F(1,84)=7.13$, $p<0.05$; $F(1,84)=10.36$, $p<0.01$). The sediment MPI_8 also indicated higher levels of trace metals in 2014 than 2015 ($F(1,84)=20.53$, $p<0.0001$).

A limited number of sediment trace metal concentrations were higher in winter than summer, including, sediment As ($F(1,84)=5.15$, $p<0.05$), Cd ($F(1,84)=2.83$, $p<0.01$), and the MPI_8, especially in winter 2014 ($F(1,84)=2.59$, $p<0.05$). There was no seasonal variation for Co, Cr, Cu, Mn, Ni, Pb, and Zn ($p>0.05$).

Two sites, Koukourārata and Heathcote, generally had higher concentrations of trace metals compared to all other sites. The indicator of metal pollutants, the sediment MPI_8, was significantly elevated at both Koukourārata pā and Heathcote, and lowest at Tern and Rāpaki beach ($F(9,84)=12.36$, $p<0.0001$). Sediment Cr and Mn concentrations were elevated at Koukourārata pā ($F(9,84)=30.78$, $p<0.0001$; $F(9,84)=10.25$, $p<0.0001$), whereas sediment Cd and Zn were elevated at Heathcote (DF=9, $F(9,84)=4.62$, $p<0.001$; $F=10.89$, $p<0.0001$). Sediment As was elevated at all Banks Peninsula sites (Rāpaki beach and rocky, Koukourārata pā and rocky; $F(9,84)=16.17$, $p<0.0001$). Sediment Co was elevated at both Koukourārata pā and rocky ($F(9,84)=19.16$, $p<0.0001$). Sediment Cu was elevated at the low salinity sites of Heathcote, SCR, and PJ ($F(9,84)=9.58$, $p<0.0001$). The sediment Ni concentration was also elevated at SCR ($F(9,84)=25.85$, $p<0.0001$), and sediment Pb concentration was significantly higher at PJ, Heathcote, Rāpaki beach and rocky ($F(9,84)=15.75$, $p<0.0001$).

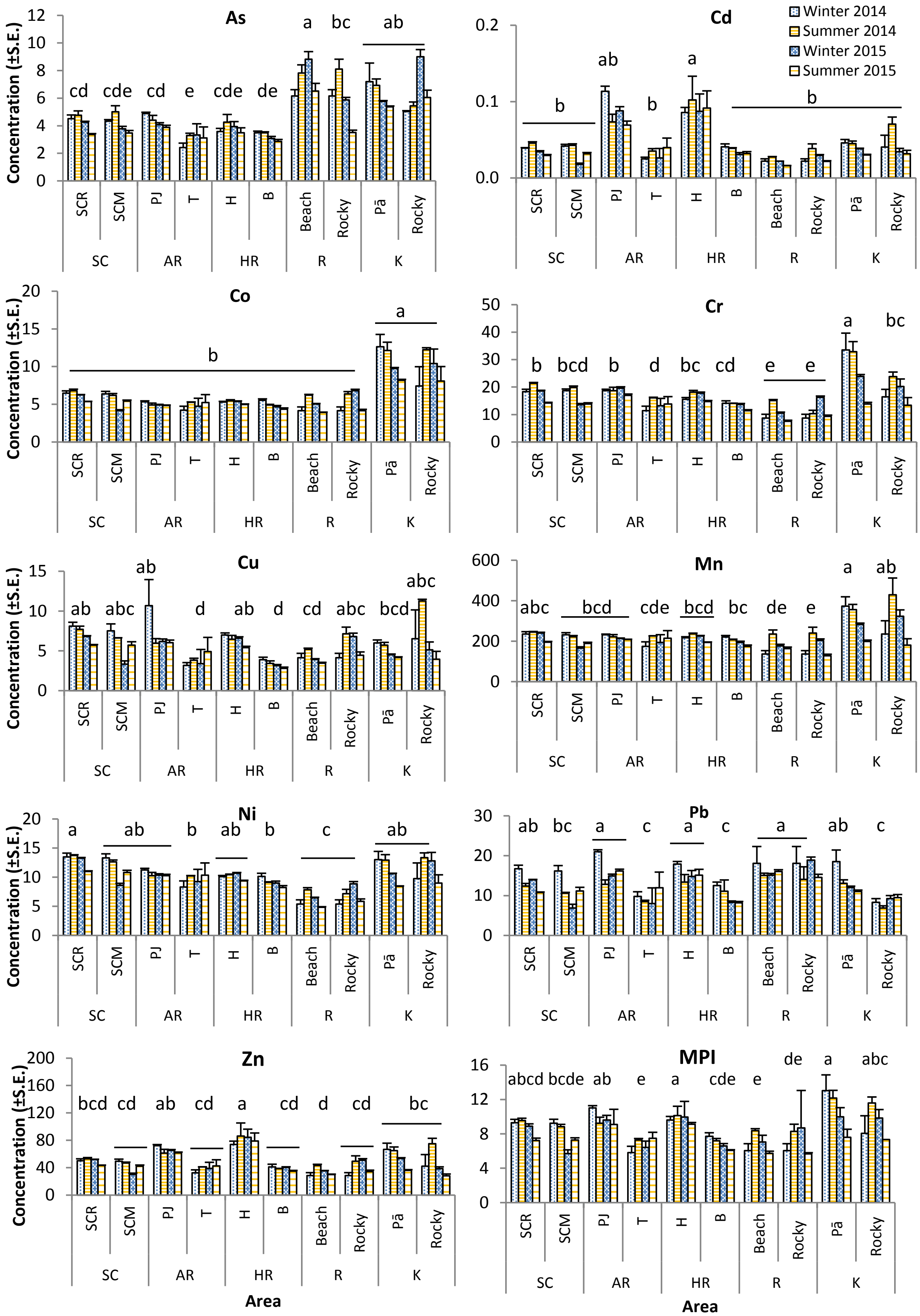


Figure 6.12. Sediment trace metal concentration (ppm dry weight) for each season. Area and site names are provided in Table 6.2. The letters indicate the post-hoc homogeneity while the horizontal line shows no temporal variability.

A. stutchburyi tissue analysis

A. stutchburyi tissue trace metal concentrations (ppm dry weight) were analysed from eight sites Saltwater Creek River and Marine (SCR and SCM), Pleasant Point Jetty (PJ), Tern (T), Heathcote (H), Beachville (B), Rāpaki (R beach) and Koukourārata pā (K pā) (Figure 6.13). The mean shell length and soft tissue weight range was between 21.48-37.61 mm and 0.09-0.61 g, respectively. The tissue concentrations were as follows: As (15.01-45.41 ppm), Cd (0.14-0.56 ppm), Co (0.60-1.63 ppm), Mn (8.82-30.50 ppm), Ni (2.49-5.11 ppm), and Pb (0.16-1.82 ppm), Zn (49.52-105.50 ppm), and the MPI_8 (2.28-4.91 ppm). The mercury results were variable and problematic, and excluded from the results analysis. The trace metal recoveries of the Certified Reference Material (CRM) and limit of detection are provided in Appendix 2.5.

All tissue concentrations, except Cu and Zn, varied with site (Figure 6.13; Appendix 6.6). Tissue As concentrations were highly variable at each site, with elevated concentration at PJ, and lower at Beachville ($F(7,101)=2.47$, $p<0.05$). Tissue Cd and Co concentration were elevated at SCR and SCM ($F(7,101)=3.05$, $p<0.05$; $F(7,101)=3.05$, $p<0.05$). Tissue Cr and Ni concentrations were elevated at Heathcote ($F(7,101)=2.27$, $p<0.05$; $F(7,101)=2.44$, $p<0.05$). Tissue Pb concentration was elevated at Heathcote and PJ ($F(7,101)=5.11$, $p<0.0001$). Tissue Mn was elevated at Rāpaki beach and similar across most sites ($F(7,101)=2.12$, $p<0.05$). Tissue MPI_8 was elevated at the low salinity site of PJ ($F(7,101)=2.95$, $p<0.05$).

Tissue Cu concentration was the only trace metal that varied by year, which was elevated in 2014 ($F(1,101)=6.48$, $p<0.05$). Tissue zinc did not vary. None of the trace metal concentrations were significantly different across season.

Correlation of the population indices, abiotic variables, and trace metal concentrations

The tissue metal concentrations correlated to the cockle population indices and to sediment metals (Appendix 6.6). The tissue MPI_8 was negatively correlated with recruit density, mean density, mean shell length, and the CI ($R=-0.26$, $p<0.01$; $R=-0.45$, $p<0.0001$; $R=-0.39$, $p<0.0001$; $R=-0.47$, $p<0.0001$, respectively). The CI was also negatively correlated with sediment MPI_8 and tissue *E. coli* concentrations ($R=-0.24$, $p<0.05$; $R=-0.31$, $p<0.01$). In addition, multiple sediment metals were negatively correlated with recruit density and CI as given in the table (Appendix 6.6).

The landscape metrics were similarly correlated with sediment contaminants but differed to tissue contaminants (Appendix 6.7). The LDI and impervious surface were negatively correlated with both sediment As ($R=-0.65$, $p<0.0001$; $R=-0.34$, $p<0.001$, respectively) and Co ($R=-0.36$, $p<0.001$, R=-

0.32, p<0.01, respectively) and were positively correlated with sediment Cd (R=0.47, p<0.001; R=0.37, p<0.0001, respectively) and Zn (R=0.28, p<0.01; R=0.25, p<0.05, respectively). The LDI was negatively correlated with tissue Mn (R=-0.53, p<0.0001) and positively to tissue As, Cd, and Zn (R=0.41, p<0.0001; R=0.33, p<0.001; R=0.36, p<0.001, respectively). Impervious surface was negatively correlated with tissue Cd and positively to tissue As and Pb (R=-0.33, p<0.01; R=0.30, p<0.01; R=0.37, p<0.001, respectively).

Many of the sediment trace metals were correlated with fine grain (>125 µm) and silt (<63 µm) composition than other grain sizes (no table). Fine grain was negatively correlated with sediment As, Co, Cr, Cu, Mn, Ni, and MPI_8 (R=-0.42, p<0.0001; R=-0.61, p<0.001; R=-0.37, p<0.001; R=-0.39, p<0.0001; R=-0.38, p<0.001; R=-0.48, p<0.0001; R=-0.30, p<0.01, respectively). Conversely, silt positively correlated with all sediment trace metals (p<0.01), except sediment As concentration.

P. australis and *T. chilensis* tissue analysis

Paphies australis tissue trace metal concentrations (ppm dry weight) as illustrated in Figure 6.14 are as follows: As (8.87-14.23 ppm), Cd (0.14-0.21 ppm), and Co (0.06-1.19 ppm), Cr (0.90-1.29 ppm), Cu (4.43-7.89 ppm), Mn (70.62-188.05 ppm), Ni (0.60-1.02 ppm), Pb (0.69-1.48 ppm), Zn (34.56-59.22 ppm), and MPI_8 (2.22-3.86 ppm). The mean shell length and soft tissue weight was 45.74±2.71-48.81±4.02 mm and 0.56±0.07-0.63±0.18 g, respectively. Tissue concentrations did not significantly vary over time (p>0.05).

The *T. chilensis* tissue trace metal concentrations ($\mu g\ g^{-1}$ dry wgt) as illustrated in Figure 6.14 are as follows: As (8.57-17.02 ppm), Cd (0.85-3.74 ppm), Co (0.31-0.54 ppm), Cr (0.40-1.31 ppm), Cu (44.17-156.30 ppm), Mn (21.47-37.51 ppm), Ni (0.42-0.93 ppm), Zn (571.59-1495.98 ppm), and the MPI_8 (3.19-5.63 ppm). The mean length and soft tissue weight were 27.64±3.91-37.78±4.39 mm and 0.11±0.03-0.40±0.09g, respectively.

The *T. chilensis* tissue trace metal concentrations were influenced by sites and year, and season (Figure 6.15, Table 6.11). Across sites, tissue Cd was elevated at Koukourārata (U=91, p<0.0001), and tissue Cu and Zn were elevated at Rāpaki (U=21, p<0.0001; U=77, p<0.0001, respectively). Elevated in 2014 compared to 2015 were tissue As, Cr, and the MPI_8 (U=181, p<0.05; U=145, p<0.05; U=94, p<0.001, respectively). Elevated in summer compared to winter were tissue Cd, Co, Cr, Mn, Ni, and the MPI_8 (U=179, p<0.05; U=121, p<0.01; U=149, p<0.05; U=175, p<0.05; U=63, p<0.0001; U=94, p<0.001, respectively).

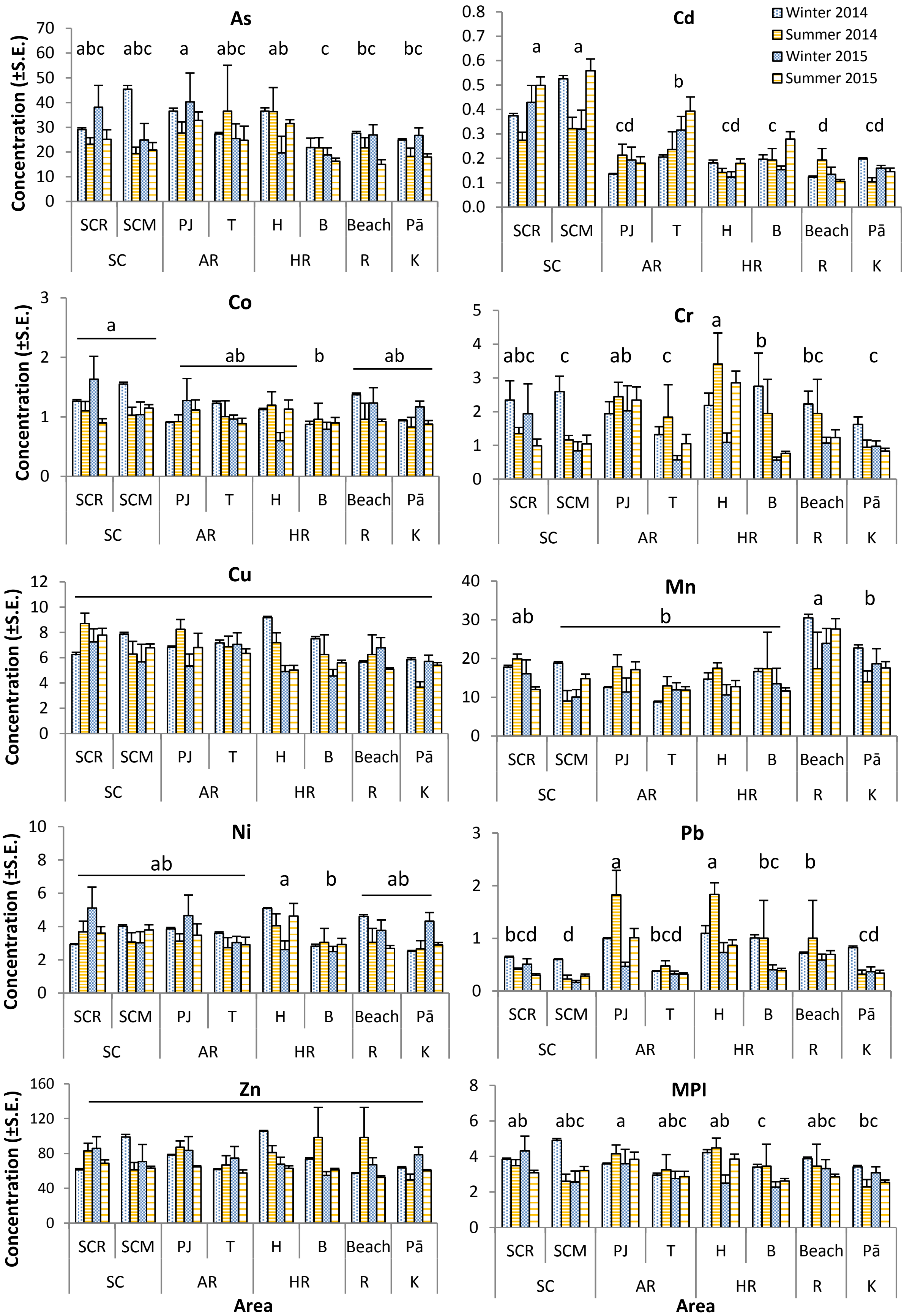


Figure 6.13. Trace metal concentration (ppm dry weight) and the Metal Pollution Index (MPI8) of *A. stutchburyi* tissue for each season. Area and site names are provided in Table 6.2. The same letters show temporally similar post-hoc values, while the horizontal line shows no temporal variability.

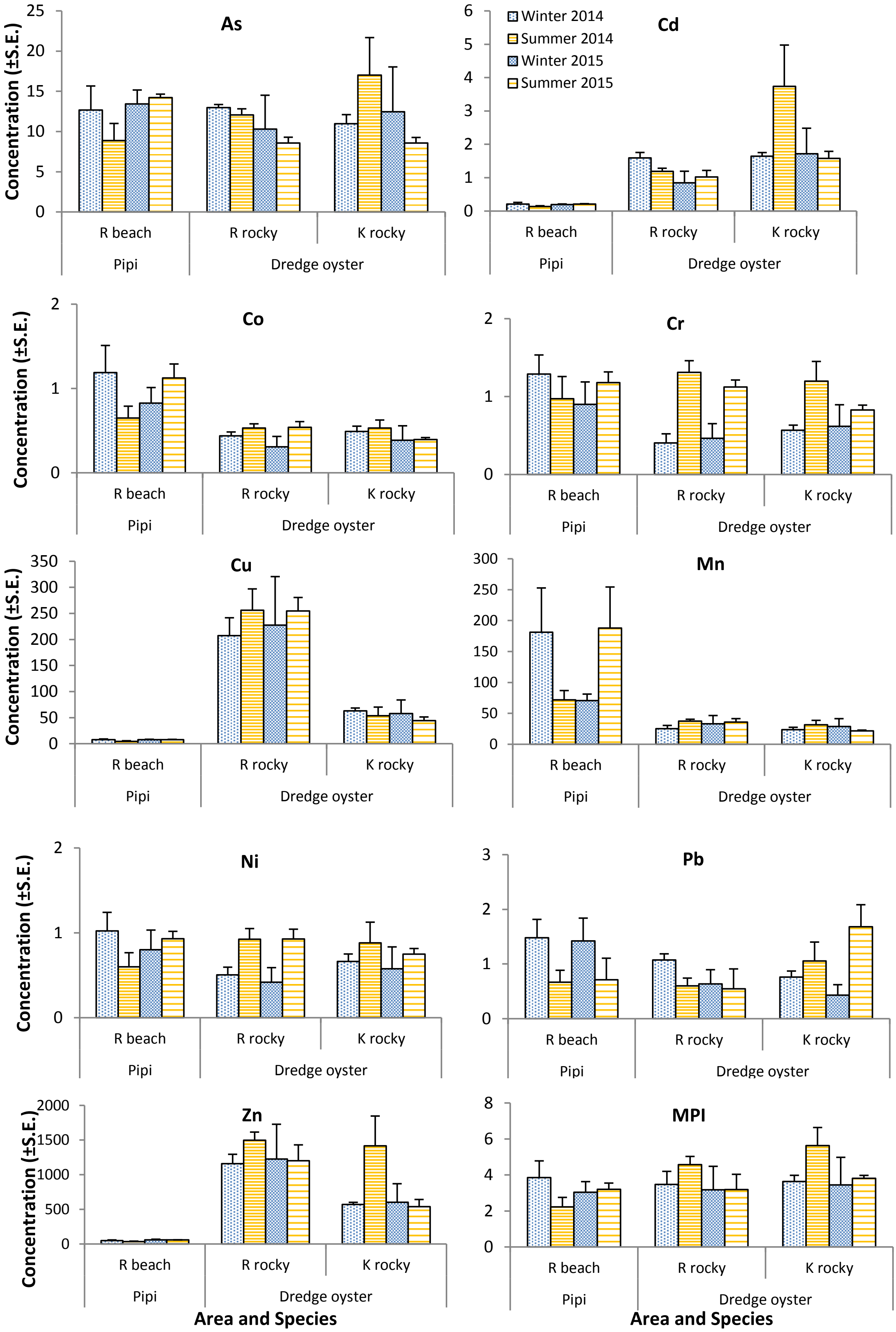


Figure 6.14. Trace metal concentration (ppm dry weight) and the Metal Pollution Index (MPI8) of pipi (*P. australis*) at Rāpaki (R) beach, and dredge oysters (*T. chilensis*) at Rāpaki and Koukourārata (K) rocky sites, at each season.

6.3.5. *E. coli* concentrations and correlation analysis

The sediment *E. coli* concentration was below detection limits (<2 MPN/100g) for many sites with one exception during winter 2014, when it reached much higher concentrations at SCR (350 MPN/100g; Table 6.6). Sediment *E. coli* did not vary between sites or season, but was higher in 2014 compared to 2015 ($U=56.5$, $p<0.05$, no table).

The *A. stutchburyi* tissue *E. coli* concentration was significantly higher in winter compared to summer ($U=28$, $p<0.01$), and did not vary across year or sites (Table 6.7). *P. australis* tissue *E. coli* was only measured at Rāpaki, and this concentration did not exceed 30 MPN/100g (Table 6.7).

The correlation between tissue *E. coli* with biological indices and water quality are as follows (Appendix 6.7). The cockle tissue *E. coli* was negatively associated with condition index ($R=-0.31$, $p<0.01$), salinity ($R=-0.49$, $p<0.0001$), and temperature ($R=-0.49$, $p<0.0001$).

Table 6.6. Sediment *E. coli* concentration (MPN/100g) at each site and season (n.v. is no value). Site names are provided in Table 6.2.

Catchment area	Site	Winter 2014	Summer 2014	Winter 2015	Summer 2015
Saltwater Creek	SCR	350	2	<2	<2
	SCM	<18	<2	<2	<2
Avon-Heathcote Estuary	PJ	<2	4	<2	<2
	Tern	<2	<2	<2	<2
	Heathcote	20	8	<2	<2
	Beachville	<18	<2	<2	<2
Rāpaki	Beach	<2	<2	<2	<2
	Rocky	n.v.	n.v.	<2	<2
Koukourārata	Pā	<2	<2	<18	<2
	Rocky	<18	<18	<2	<2

Table 6.7. Tissue *E. coli* concentration (MPN/100g) of *A. stutchburyi* at each site, *except Rāpaki which *P. australis* was sampled. Site names are provided in Table 6.2.

		2014		2015	
Area	Site	Winter	Summer	Winter	Summer
Saltwater Creek	SCR	330	110	50	490
	SCM	130	<20	20	490
Avon-River	PJ	80	90	20	330
	Tern	230	20	20	<20
Heathcote-River	Heathcote	330	170	50	220
	Beachville	130	20	20	20
Rāpaki	*Beach	20	20	<30	<20
Koukourārata	Pā	50	20	50	<20

6.4. Discussion

6.4.1. *A. stutchburyi* population biology, distribution, and structure

In the present study, the population density and structure of *A. stutchburyi* were variable across sites. This was attributed to population variability and environmental conditions. Globally, bivalve density and structure (including recruitment) has been linked to population variability (Flach 1996, Gam et al. 2010, Genelt-Yanovskiy et al. 2010), watershed land use (Hale et al. 2004, King et al. 2005), water quality parameters (Craig 1994, Defeo and de Alava 1995, Carmichael et al. 2004, Gagné et al. 2008), and sediment characteristics (Arbuckle and Downing 2002, Herrmann et al. 2009). Bivalve condition and abundance were also negatively associated with trace metal contamination (Luoma et al. 1990, Weisberg et al. 1997, Stark 1998, Cheggour et al. 2001, Nunes et al. 2008).

Natural population variability

In the present study, the *A. stutchburyi* density varied between 7 and 256 clams m^{-2} within sites over time as well as across sites. In Adkins (2012) and the present study, site-specific annual variability occurred. It has been suggested that temporal fluctuations in density are generally less than spatial variation (Edgar and Barrett 2002). The present density was lower than previously found (~200 to >3000 clams m^{-2}) at Saltwater Creek Estuary, Avon-Heathcote Estuary and Koukourārata pā (Adkins 2012). This difference could be due to spatial variability (i.e. low versus mid intertidal zone). *Austrovenus stutchburyi* density tends to peak at mid-tidal level (McArdle and Blackwell 1989). In another study, *A. stutchburyi* densities were higher in the mid-intertidal zone (200-600 clams m^{-2} and 300-600 clams m^{-2}) compared to the low-intertidal zone (50-380 clams m^{-2} and 300-680 clams m^{-2}) at Mana and Pauatahanui sites in Wellington (Michael 2008).

The *A. stutchburyi* population structure represents the stability of a population as well as recruitment episodes. The present study population structure was variable within sites over time and across sites, as found in other infaunal bivalve studies (Flach 1996, Gam et al. 2010, Genelt-Yanovskiy et al. 2010). The population structure in the present study was dominated by large individuals with low juvenile recruitment densities (Figure 6.5-6.8; Appendix 6.3). Additionally, higher juvenile cockle recruitment occurred in 2015 than in 2014. These findings concur with the finding that *A. stutchburyi* recruitment is irregular (Kainamu 2011, Adkins 2012) and that settlement is variable from year to year and between different areas (Larcombe 1971). The seasonality effect was not observed in the present study compared with previous local findings (Adkins et al. 2016).

Similar to mean density, the recruitment density values (0-48 clams m^{-2}) were much lower than previously reported (~10-600 clams m^{-2}) at Saltwater Creek Estuary, the Avon-Heathcote Estuary, and

Koukourārata pā (Adkins 2012). This is likely due to spatial variability across the intertidal zone. The comparison of bivalve settlement across the intertidal zone found high *Macoma balthica* densities settled within the low intertidal zone of the Wadden Sea (Günther 1991) compared to high settlement of *M. balthica* and *Cerastoderma edule* densities within the low intertidal zone of the Westershelde estuary (Bouma et al. 2001). The latter study suggested that larval cockles prefer to settle in particular environmental conditions (sediment characteristics and hydrology) and that this can vary between Westershelde Estuary and Wadden Sea (Bouma et al. 2001). The current findings illustrate that site-specific recruitment density within the lower intertidal zone may contribute to the population (e.g. Heathcote recruitment was 6-48 clams m^{-2}). Evidence supports the relocation of small bivalves to higher parts of the tidal flat (Günther 1991) and away from less-preferred sediments via a series of migrations (Huxham and Richards 2003).

Landscape development, sediment and salinity effects

Landscape condition affects ecological communities through direct, secondary, and cumulative impacts (Brown and Vivas 2005). In the present study, recruitment density was influenced by watershed landscape develoment, and both recruitment and mean density were influenced by sediment characteristics. Recruitment was positively correlated with urbanised watershed landuse rather than with rural areas, which disagrees with *A. stutchburyi* recruitment density patterns in Auckland estuaries (Stewart 2006). Unlike other studies, the landscape development indices in the present study do not include the associated sediment characteristics and other environmental inputs (Hale et al. 2004). The landscape metrics alone discriminated between low and high benthic environmental quality (BEQ) and *Macoma mitchelli*, a pollution sensitive species, was reduced at low benthic environmental quality (BEQ) stations (Hale et al. 2004). Additionally, a multivariate model found the abundances of *M. balthica* and *M. mitchelli* were associated with forested and mixed land use in combination with wetlands and muddy composition at moderate-to-high salinities within Chesapeake Bay (King et al. 2005). However, only 25% of the variation in bivalve abundance was explained by this pattern (King et al. 2005), which suggested further variables, such as environmental quality including sediment contamination, could be unaccounted for. Considering sediment composition, the present study findings are similar to previous research, which found *A. stutchburyi* recruitment was positively associated with fine sand composition and negatively associated with silt (Stewart 2006, McConway 2008). Inorganic silts and clays directly affect filter-feeders by clogging feeding structures, interfering with particle selection and requiring the use of energy to clear away underwater particles (Thrush et al. 2004).

In the present study, *A. stutchburyi* density (7 and 256 clams m^{-2}) was negatively affected by low salinity exposure (Figure 6.5-6.8; Appendix 6.3). However, two sites were an exception to this: with low salinity, Heathcote had relatively high cockle densities (73-180 clams m^{-2}), while Rāpaki, with high salinity, had very low cockle densities (7-40 clams m^{-2}). It is possible that high nutrient levels benefitted Heathcote cockle densities, while the sediment composition of Rāpaki negatively influenced cockle densities. Salinity is known to positively influence bivalve density (Marsden and Pilkington 1995, Carmichael et al. 2004, Adkins 2012). Previous studies have demonstrated that exposure to low salinity limited growth in *Mercenaria mercenaria* and *Mya arenaria* clams, although salinity only had a moderate effect where there was increased food supply (Carmichael et al. 2004). Similarly, *A. stutchburyi* was shown to tolerate prolonged exposure to low salinity as long as nutrient quality and quantity were adequate; if not, speciments became stressed and lost condition and weight (Marsden 2004). Due to the earthquake damaged waste-water infrastructure in recent years, raw sewage was directly discharged into the rivers entering the Avon-Heathcote Estuary or into theestuary itself, increasing the amount of nutrients available (Adkins 2012). Over this time period, *A. stutchburyi* density increased in the Avon-Heathcote Estuary from <200 to 200-300 per m^2 at the low salinity site (Bromley) and from 500-1,000 per m^2 to 1,500-2,000 per m^2at the high salinity site (Tern) (Adkins 2012). Therefore, the effect of low salinity on the cockle density at Heathcote could be negated by elevated nutrient supply.

The reduced cockle density at Rāpaki was most likely due to the relationship between bivalves (both *A. stutchburyi* and *P. australis*) and sediment characteristics (Thrush et al. 2003, Anderson 2008). In the present study, the Rāpaki clam beds were predominantly composed of medium and coarse sands, compared to finer sands (silt, very fine, and fine sand) at the other sites (Figure 6.3). Medium sand composition negatively correlated with *A. stutchburyi* density while coarse sand negatively correlated with recruitment density and fine sand positively correlated with recruitment density. Therefore, the Rāpaki sediment composition did not correlate with juvenile or adult cockles compared with successful juvenile recruitment at all other sites.

Contamination effects

This present study is the first evaluation of a suite of contamination (trace metal and *E. coli*) in shellfish and sediment samples across Canterbury estuaries, alongside socio-cultural values (Chapter 5). In the present study, *A. stutchburyi* density was negatively associated with elevated sediment arsenic, copper, and lead concentrations. Previously, *A. stutchburyi* density has been negatively correlated with sediment concentrations of lead (Adkins 2012), cadmium and zinc (McConway 2008). Bivalve abundances have also been found to be low in estuarine sites of elevated sediment metal contamination (Stark 1998, Nunes et al. 2008), including copper, lead and zinc (Stark 1998). Manipulative experiments of elevated sediment metals (copper, lead, and zinc) however, did not adversely affect *A. stutchburyi* abundances compared to other macrobenthic species (Fukunaga and Anderson 2011). It is not conclusive that elevated sediment metals affect *A. stutchburyi* abundance, however the negative correlations in the field could suggest that sediment metals is associated with another stressor that impacts this shellfish species. In this study, *A. stutchburyi* tissue metal concentrations correlated positively with particular sediment metlas and negatively with density. Given that bivalve tissue metal uptake is associated with sediment metal concentrations (Griscom and Fisher 2004, Usero et al. 2005), it suggests sediment contamination could be a stressor to bivalves and that further understanding of the effects of contaminants on bivalves is necessary.

Austrovenus stutchburyi density in the present study was also negatively associated with elevated trace tissue arsenic, cobalt, chromium, nickel concentrations and with tissue Metal Pollution Index (MPI_8). There is a paucity of information on the effect of tissue contamination with *A. stutchburyi* density. In agreement with Adkins and Marsden (2009), tissue contaminants may explain differences in *A. stutchburyi* population characteristics, depending on the influence to reproduction and recruitment. The influence on reproduction and recruitment are indicated by the condition index (CI), which has been closely associated with the bivalve reproductive cycle (Roper et al. 1991, Ojea et al. 2004). In the present study, negative correlations occurred between the CI and contamination (sediment MPI_8, tissue MPI_8 and tissue *E. coli*),while recruitment negatively correlated with tissue MPI_8. However, sites with the highest sediment MPI_8 concentration (Heathcote and Koukourārata pā) had contrasting CI concentrations. Conversely, sites with elevated tissue MPI_8 and tissue *E. coli* coincided with low CI (Heathcote and PJ), low mean density and recruitment density (PJ and SCR). In other studies, the tissue metal concentration in *C. edule* has been seasonally related to the reproductive cycle (Cheggour et al. 2001). The CI also indicates underlying trace metal body burden in *C. edule* (Anajjar et al. 2008); this was similarly observed in *A. stutchburyi* CI and length, which was impaired by tissue MPI burden (Marsden et al. 2014). Seasonal variation in either CI or recruitment was not observed in the current study; the difference instead was site-specific. Although the cockle samples from Heathcote were indicative of tissue contamination stress, this site had successful recruitment during each season and recruitment density was on par with low contamination sites (Beachville and Tern). Conversely, the other contaminated sites (PJ and SCR) had poor recruitment. The constant recruitment strategy has been found in both cockles and pipi (Hooker and Creese 1996, Stewart 2006, Adkins et al. 2016), is suggested to occur at Heathcote, which may support the current population numbers.

6.4.2. *P. australis and T. chilensis* population biology, distribution and structure

One of the objectives of both Rāpaki and Koukourārata mātaitai reserves is to ensure the sustainability of the fisheries resource and its environment (Mudunaivalu 2013). Very little research has been done to identify the status of multiple species at both mātaitai reserves. This is the second survey of *P. australis* at Rāpaki, the first of at *A. stutchburyi* Rāpaki, and first of *T. chilensis* at both sites.

In the present study, the *P. australis* population density range was 178 to 393 clams m^{-2} and did not vary over time. This density was far lower than found previously at either Rāpaki reserve (4968 m^{-2}) or the non-reserve site at Corsair Bay (2,441 m^{-2}) (Mudunaivalu 2013). There are differences in the sample size used, a 0.1 m² quadrat was utilised in the present study compared to a 12.5 cm² core used previously (Mudunaivalu 2013). The present size distribution was predominantly composed of mature size clams and clam length was generally larger than previous found at Rāpaki (Mudunaivalu 2013). This is likely due to increasing size distributions within the lower intertidal gradient, as evident at Rāpaki and Corsair Bay (Mudunaivalu 2013) and Whangateau Harbour (Hooker 1995). Unlike Mudunaivalu (2013), this present study focussed on the 40 m zone, which did not include smaller pipi from higher in the intertidal zone. Mudunaivalu (2013) surveyed along the shore between 20 m and 40 m, and found that pipi at the lower shore distance (>40 m) were mostly adults.

Similar to other bivalve studies (Bouma et al. 2001, King et al. 2005, Herrmann et al. 2009), the *P. australis* density was influenced by sediment composition and intertidal distribution. Mudunaivalu (2013) found *P. australis* abundances decreased in the lower intertidal zone at Corsair Bay, which coincided with silt/clay sediment composition. The relationship between both bivalve species and sediment characteristics was evident in other New Zealand studies (Thrush et al. 2003, Anderson 2008). An example of an animal-sediment relationship showed a predominance of *P. australis* at the sandy end of the sediment grain size spectrum, which shifted *A. stutchburyi* when moving along the gradient towards more mud (Anderson 2008). In the present study, Rāpaki beach was characterised by medium and coarse sand composition, which coincided with the very abundant *P. australis* population (178-393 clams m^{-2}) and the lowest *A. stutchburyi* population (7-40 clams m^{-2}) compared to other sites.

In other bivalve studies, condition index (CI) and recruitment density followed a seasonal pattern (Roper et al. 1991, Hooker 1995, Marsden and Pilkington 1995, Mudunaivalu 2013). In this study, seasonal patterns of *P. australis* CI were significantly higher in summer than in winter, suggesting an accumulation of reproductive tissue. In addition, a higher number of juvenile recruited into the population during winter. Both patterns concur with previous findings (Mudunaivalu 2013).

In the present study, *T. chilensis* population density along the Rāpaki and Koukourārata rocky shores was very sparse (2.5-4.5 oysters m^{-2}). This was especially the case with mature sized oysters (>50 mm at <0.5 oysters m^{-2}) and harvestable oysters only present for one sampling period at each site. Missing cohorts in a size frequency histogram may indicate a difference in survival of small and large individuals (Wenner 1988). In the present study, local oysters were perceived to be abundant with harvestable sizes present. It is difficult to detect stressors in an already declined population, and without any previous *T. chilensis* studies. The Local Practitioners and Specialists interviews described other populations around the coastline at Koukourārata that were still abundant and in the past that existed on Horomaka Island (adjacent to Koukourārata pā). Shell middens at Horomaka Island were dominated by rocky shore species, including oysters (Challis 1995). The oyster populations in this study did not reach mature size and were predominantly juveniles, suggesting that a spawning stock may be in the estuary that was not included within this survey. Guidance from LPS in future could assist locating existing oyster sites. There is a paucity of information on this once-harvested species, which likely contributed to ecosystem services at these locations.

The existing knowledge of dredge oysters is often limited to anectodal accounts, where strong declines have occurred, which appear largely attributable to land-based and fishing pressure (Morrison et al. 2014a). It is speculated that the mature breeding stock of these populations exist elsewhere in the bay and that the perceived changes to environmental condition (hydrology, sediment characteristics) and nutrient supply (potentially from mussel farming), could be affecting these populations. A study of experimental oyster (*Crassostrea virginica*) reefs suggested that the reefs' physical condition had a profound influence on the performance of oysters, and water flow alone explained 81% of the variability in oyster growth and mortality (Lenihan 1999). In addition, the physical structure and location of experimental oyster reefs can controls local physical variables (e.g. water flow) (Lenihan 1999). Therefore, existing biogenic habitats (oysters and their reef systems) support the performance of resident species. Within another *C. virginica* study, high densities appeared to be supported by high existing (empty) shell structures, while the opposite was true for low density oysters (Mann et al. 2009). Given this information, further research is required to understand the stressors that impact *T. chilensis* populations and the development of restoration methodologies is urgently, given the beneficial role filter feeders play within estuarine systems as well as their importance to social, cultural, and commercial fisheries.

6.4.3. Guideline levels for sediment and tissue contaminants

The sediment trace metal concentrations (ppm dry weight) were compared to the Interim Sediment Quality Guidelines (ISQG) in Table 6.8 (ANZECC and ARMCANZ 2000). None of the sediment metals had exceeded the ISQG, indicating that they are unlikely to have an ecological effect. There is no sediment *E. coli* standard against which comparisons can be made. It is worth mentioning that the Australian and New Zealand Guidelines for fresh and marine water quality and sediment quality have recently been reviewed and updated (Simpson et al. 2013, Warne et al. 2013, Batley et al. 2014, Warne et al. 2015). The former has made change so water sample quality and not the tissue contaminants, only the latter was measured in this study. The recommended sediment quality guidance (SQG) values (Simpson et al. 2013) for the metals measured in this study (As, Cd, Cr, Cu, Pb, Ni, and Zn) are no different to the current interim sediment quality guidance (ISQG) values. However, further lines of evidence may implicate current findings if local biota toxicity are found to be more sensitive to environmental contamination.

Shellfish tissue trace metal concentrations were converted to wet weight and compared to the Australia and New Zealand Guidelines for Fresh and Marine Water Quality (FSANZ 2015). In addition, tissue inorganic arsenic ($\mu g\ g^{-1}$ wet weight) concentration were calculated for each species; this ranged from 0.3-1.2 ppm for *A. stutchburyi*, 0.3-0.6 ppm for *P. australis*, and 0.1-0.4 ppm for *T. chilensis*. *A. stutchburyi* tissue inorganic arsenic concentration exceeded the guidance level (1.0 ppm) at the low salinity rural site of Saltwater Creek River (SCR) during winter 2015 (1.17±0.5 ppm). Additionally, the present *A. stutchburyi* tissue arsenic concentrations correlated positively with the Landscape Development Intensity (LDI) index and negatively to salinity, which coincides with the high concentrations at PJ and SCR. Tissue values exceeding safe values for arsenic at Saltwater Creek have previously been reported (Adkins and Marsden 2009). *A. stutchburyi* tissue cadmium and lead trace metal concentrations did not exceed guidance levels, nor did *P. australis* and *T. chilensis* tissue trace metal concentrations.

Shellfish tissue *E. coli* concentrations (MPN: Most Probable Number/100g) were compared to the guideline level (230 MPN/100g) for the protection of human consumers of fish and other aquatic organisms (ANZECC and ARMCANZ 2000). *A. stutchburyi* tissue *E. coli* concentration exceeded guidance levels at SCR and Heathcote during winter 2014 and at SCR, Saltwater Creek Marine (SCM) and PJ during summer 2015 (Section 6.3.5). All of these sites were low salinity sites except SCM. However, SCM has previously been found to have low salinity and unlike the present study, Adkins (2012) found that the salinity levels at SCM and SCR were not significantly different. In addition, the water quality at low salinity sites of both the Rakahuri/Ashley River-Saltwater Creek and Avon-Heathcote estuaries have previously been found to exceed either the standards for recreational safety or shellfish consumption safety (Pauling et al. 2007, Lang et al. 2012, Bolton-Ritchie 2016). The *P. australis* tissue *E. coli* concentrations at Rāpaki beach did not exceed guidance level for safe consumption.

6.4.4. Sediment and shellfish tissue contaminant concentrations

Chemical contamination, sewage and organic wastes and human-induced sediment/particulate inputs are within the top five stressors to estuarine ecosystems globally (Kennish et al. 2014) and within New Zealand (Stevens and Robertson 2012). In this study, the microbial indicator for faecal matter (*E. coli*), chemical contamination and sediment composition were associated with poorer environmental conditions as well as shellfish health. The sources of contamination can be linked to the weathering of volcanic rocks (e.g. manganese), run-off from mobile soil (e.g., phosphate fertiliser) or anthropogenic sources (Table 7.1: Chapter 7). Examples of the latter sources include post-earthquake damage and repair work (e.g., direct sewage sludge discharge) and industrial processes that are no longer permitted to discharge their waste into waterways.

Sediment composition, trace metal and *E. coli* concentrations

Although controversial, in recent times sediment has been considered a contaminant due to elevated sedimentation regime to estuarine and coastal systems (Thrush et al. 2004). Sedimentation within estuaries is natural and provides a number of important functions (e.g. supplying nutrients or burying contaminated sediments); however, environmental problems occur when the rate at which sediment is transferred to and deposited within estuaries increases (Thrush et al. 2004). Fine sediment can transport contaminants and result in benthic smothering (Davies- Colley and Smith 2001a). In the present study, higher silt composition was found at the rural sites Saltwater Creek (SCR-SCM) and Koukourārata pā (both of which are both predominantly highly-productive pasture (70.5% and 97.8%, respectively; Figure 6.2) than at the urban Avon-Heathcote Estuary. Pasture produces 2-5 times more sediment than an equivalent area of forest (Parliamentary Commissioner for the Environment NZ 2012).

Trace metal concentrations in benthic sediment have been extensively studied in the Thames Estuary (United Kingdom) and have been linked to past and present industrial and urbanised runoff (Attrill and Thomes 1995). In the present study, the sediment MPI_8 data (Figure 6.13) identified Koukourārata pā and Heathcote sites as the most polluted. Koukourārata pā had the highest chromium concentration while Heathcote had the highest cadmium and zinc concentrations. The sediment copper concentration was elevated at Heathcote, SCR and PJ while sediment lead concentrations were elevated at Heathcote, PJ, Rāpaki beach and Rāpaki rocky sites. Sediment *E. coli* concentrations were not considered a major issue in the present study, given the very low concentration range (<2 to 20 MPN/100g), except during summer 2014 at SCR (350 MPN/100g).

Elevated sediment contamination concentrations at Koukourārata pā and Heathcote were likely due to the location within the estuary and the catchment land-uses. Both sites are situated nearer the head of the estuary and have narrow mouth inlets. Additionally, within this study, the correlation between the Landscape Development Intensity (LDI) index and impervious surface area with sediment metals distinguished between urban sourced metals (cadmium and zinc), which were highest at Heathcote, and rural sourced metals (arsenic, cobalt and manganese), which were highest at Koukourārata. Elevated sediment input and sediment contamination has been linked to land-use/land-cover or landform characteristics (Comeleo et al. 1996, Wemple and Jones 2003, Valentin et al. 2008). Within Chesapeake Bay estuaries, the area of developed land located in the watershed within 10 km of the sediment sampling station is a major contributing factor to sediment metal concentrations (Comeleo et al. 1996). In the impacted Tamaki Estuary in Auckland, increased sediment metal concentrations, especially towards the head of the estuary, are associated with catchment industrialisation and urbanisation (Abrahim et al. 2007). .

Environmental parameters such as sediment grain size and contamination levels can vary greatly through time and space and be influenced by heavy rain and sediment transport (Hicks 1993, Thrush et al. 2004, Fletcher 2010). In the present study, high silt composition and sediment metal concentrations were found at Koukourārata pā and Heathcote (both of which are near the estuarine head). Percent silt was also positively correlated with sediment trace metal concentrations (except arsenic). A coastal hydrodynamics study within Port Levy suggested that suspended sediment is transported towards the head of the bay and that loess soil (which is predominantly silt-sized sediment) from the surrounding slopes is likely the main source of sediment entering the bay, deposited during high wind and rainfall events (Fletcher 2010). Both Adkins (2012) and participants interviewed (Chapter 5) had observed increased run-off during heavy rain at Koukourārata/Port Levy, especially during winter. Adkins (2012) also found that the Koukourārata pā and Port Levy site Fernlea had the highest sediment MPI_8. Heathcote was not included within that study.

Under stable conditions within the Avon-Heathcote Estuary, sediment yields were slightly higher at Heathcote (43-65 t/km²/yr) compared to the Avon (35-52 t/km²/yr) catchment, except during large storm events when the Heathcote (<0.01 to 68.3 t/km²/yr) was much higher than the Avon (0.01 to 32.4 t/km²/yr) catchment (Hicks 1993). This most likely reflected increasing sediment production from the Port Hills tributaries after heavy rain compared to the limited sediment supplies of the flat tributaries of the Avon (Hicks 1993). Prevention of run-off and erosion from cultivated sloping land generally included the practices of increased vegetation soil cover within a study across 27 upland catchments in Southeast Asia (Valentin et al. 2008). Further understanding of this could improve the management at sites where elevated sediment input and contaminant input occur.

The association between sediment grain size and sediment metal concentrations has yet to be confirmed in New Zealand studies. In previous studies, sediment copper and zinc correlated positively with silt and negatively with fine sands across Canterbury estuaries, including Avon-Heathcote, Saltwater Creek and Port Levy (McConway 2008). Conversely, in the present study, neither the percentage of silt nor sand composition significantly correlated with sediment trace metals (As, Cd, Cr, Cu, Ni, Pb or Zn) across the same Canterbury estuaries (Adkins 2012). Many more significant associations between land use and/or sediment contaminants with *A. stutchburyi* population density and recruitment density compared to the previous study (Adkins 2012). This could be due to the difference in the intertidal zones targeted for surveying or to temporal differences. Monitoring the condition of an estuary is complicated by the high natural spatial and temporal variability frequently associated with estuarine environments (Pridmore et al. 1990). Fine-scale monitoring of benthic characteristics across space and time require further research in New Zealand (Robertson et al. 2002).

The sediment results of this present study were compared to previous local, national, and global findings (Table 6.8). Locally, sediment arsenic levels were generally similar to previous Canterbury data, Fernlea in Port Levy was slightly higher (15.1 pm) than the present maximum concentration (9.0 ppm), but both concentrations were much lower than the geothermal site in Rotorua (880 ppm) and Restronguet Creek in the United Kingdom (1740 ppm), which is suggested to be due to metal-mining discharge (Bryan and Langston 1992). The sediment cadmium concentrations from the present study and previous Canterbury data were highest at Avon-Heathcote (0.11-0.16 ppm) but were lower than those found near Stewart Island (0.33 ppm), potentially due to mining (Frew et al. 1997). Higher concentrations have been reported within Sydney Harbour (1.0-10.0 ppm) and are likely due to the intense urbanization and industrialization of the catchment (Irvine and Birch 1998). Similarly, sediment chromium did not vary from national findings and were exceeded by urbanised estuaries in Australia and Hong Kong. Many studies did not measure sediment cobalt and manganese, and findings from this study were similar to other national and global findings. Sediment copper, lead, nickel and zinc concentrations were commonly elevated at low salinity sites (e.g. Heathcote River), although these concentrations were lower than previously reported in the Avon-Heathcote estuary (Bolton-Ritchie 2008), which also had the most elevated concentrations (13-22 ppm, 25-35 ppm and 115-156 ppm, respectively) towards the mouths of the Avon River and Heathcote River (e.g. PJ and Heathcote). Sediment copper, lead, nickel and zinc concentrations were lower than global findings, from areas of higher urban populations and longer industrialised periods than New Zealand.

Table 6.8. Trace metal concentrations in sediment (ppm dry weight) in New Zealand, including this current study (bold) and international studies. Included are the low and high Interim Sediment Quality Guidelines (ISQG). Cells are blank where there were no reported results. Abbreviated are Hong Kong (HK), Australia (AUS), and the United Kingdom (UK).

	Metal concentration (ppm)									
Area	As	Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn	Reference
New Zealand										
Tamaki Estuary, Auckland		<0.1-1.5			0.9-60.4			9-200	14.0-365.0	(Abrahim and Parker 2002)
					5.0-19.5			7.8-12.9	61.7-224.9	(Simpson 2009)
Aotea, Raglan, Auckland		0.02-0.5			6.2-37.2	86.1-352.4	3.9-34.4	4.5-256.6	21.9-230.1	(Nipper et al. 1998)
Manukau, Auckland					0.0-26.4			0.0-36.3	0.0-178.2	(Kelly 2009)
Auckland Region					2.4-40.0			3.9-37	21-195	(Reed et al. 2010)
Maketu, Rotorua	4-880	<0.01-2.5		1.0-18.0	1.0-14.0		0.0-2.0	2.0-29.0	10.0-130.0	(Phillips et al. 2014)
	3.7	<0.01		1.9	0.7		1.2	1.5	9.7	
Foveaux Strait		0.04-0.33								(Frew et al. 1997)
Christchurch, Canterbury	<2-13	<0.1-2.0		10.0-38.0	<2-22		6.0-16.0	8.0-35.0	45-156	(Bolton-Ritchie 2008)
Saltwater Creek and Christchurch	0.8-1.9		0.7-1.0	5.0-9.0	1.5-7.5	55.0-75.0	1.3-1.6	1.4-3.8	24.0-45.0	2003 data (Marsden et al. 2014)
North-to-Banks Peninsula		0.03-0.20			3.2-15.4				35.1-99.0	(McConway 2008)
	2.6-15.1	0.03-0.16		8.8-28.1	3.0-14.0		7.4-25.2	4.9-15.6	28.4-69.6	(Adkins 2012)
Saltwater Creek, Canterbury	3.5-4.8	0.03-0.04		12.8-17.8	6.2-10.6		10.5-13.9	10.3-13.6	41-56.0	(Bolton-Ritchie 2016)
North-South Canterbury	2.1-5.6	0.02-0.21		5.3-25.0	1.5-15.4		2.5-13.7	2.4-19.4	17.4-143	(Bolton-Ritchie and Lees 2012)
North-to-Banks Peninsula	**2.4-9.0**	**0.02-0.11**	**3.9-12.6**	**7.6-33.5**	**2.8-11.3**	**128.2-429.3**	**4.8-13.7**	**6.9-21.0**	**28.1-115.4**	**Present study**
International										
Tasmania, AUS		0-6.0		0-88	0-224			0-1450	0-500	(Ayling 1974)
Swan River Estuary, AUS		0.0-0.9			2.6-297.0			4.9-184.1		(Rate et al. 2000)
Sydney, AUS			4-11.0	9-89.0	68-270.0		9-40.0	88-530.0	280-1100.0	(Birch and McCready 2009)
		1-10.0		7-698.0	13-1078.0	30-408.0	17-86.0	44-1319.0	46-2246.0	(Irvine and Birch 1998)
Helford, Colne, Poole Hbr, UK	<2-50	<1-3			6-278			25-750	180-620	(Thornton et al. 1975)
Restronguet Creek, UK	1740	1.53	21	32	2398	485	58	341	2821	(Bryan and Langston 1992)
Fal, UK	56	0.78	9	28	648	272	23	150	750	
Solway, UK	6.4	0.23	6	30	7	577	17	25	59	
Ria de Aveiro, Portugal, EU	0.8-6.4	0.03-0.16		1.7-7.8	0.8-6.8		1.0-5.4	1.6-9.9	14.2-59.5	(Figueira et al. 2011)
Morroco, Mediterrenean			0.9-3.7		32.9-36.9			22.4-33.0	125-144	(Cheggour et al. 2001)
Dalian, China	3.9-4.0	0.06-0.1		15.6-44.7	11.1-22.6			7.1-18.0	37.2-59.0	(Zhao et al. 2012)
France		0.8-2.2			70-158			74-391	268-542	(Geffard et al. 2002)
Mai Po estuary, HK		1.1-1.4		20.0-74.6	51.1-87.4		43.9-86.9	68.7-219.6	129.7-307.6	(Che 1999)
Tolo Harbour, HK		2-7.0			20-150				20-190	(Chu et al. 1990)
Victoria Harbour, HK					22.0-111.0				96.0-247.0	(Phillips and Yim 1981)
Low ISQG	20	1.5	No value	80	65	No value	21	50	200	(ANZECC and ARMCANZ 2000)
High ISQG	70	10		370	270		52	220	410	

Tissue trace metal and *E. coli* concentrations

Tissue trace metal contaminants ($\mu g\ g^{-1}$ dry weight) in *A. stutchburyi*, *P. australis*, and *T. chilensis* were compared to national and global shellfish studies (Table 6.9). Despite the limited data on these species, interspecies comparisons are made but are given with caution because of the variability in metal accumulation rates among some bivalve species.

In the present study, *A. stutchburyi* tissue MPI$_8$ indicated elevated trace metal concentrations at Pleasant Point Jetty and Heathcote, both of which are low salinity sites within the urbanised Avon-Heathcote Estuary. The concentration of tissue arsenic was highest at Pleasant Point Jetty, while tissue lead concentration was highest at both the PJ and Heathcote sites. Compared to previous global studies, *A. stutchburyi* tissue arsenic concentrations exceeded other cockles and mussels, as well as the findings from *Crassostrea gigas* samples in O`ahu Hawai`i (Table 4.16; Chapter 4). The remaining tissue metal concentrations in the present study did not exceed global cockle and mussel findings. Locally, tissue arsenic exceeded previous findings by Adkins and Marsden (2009) but did not exceed the tissue arsenic concentrations of cockles collected in 2003 at Saltwater Creek and the Avon-Heathcote Estuary (Marsden et al. 2014). Many of the present cockle tissue concentrations (cadmium, chromium, cobalt, copper, lead, manganese and nickel) were similar to or lower than national findings, except for cockle tissue zinc concentration, which was higher than cockles from other Canterbury estuaries but lower than Otago Harbour concentrations.

P. australis samples from Rāpaki beach in the present study had much higher tissue manganese concentrations than global clams and mussels (Table 6.9). Nationally, the *P. australis* tissue trace metal concentration could only be compared to findings from the geothermal region of Maketu, Rotorua. Tissue arsenic was similar to pipi from Maketu, and tissue cadmium, chromium, and zinc were lower. Tissue copper was higher than in pipi from Maketu.

T. chilensis samples from Rāpaki and Koukourārata rocky sites in the present study had higher tissue copper and zinc concentrations than previous global clam and mussel findings (Table 6.9), but were lower than global *C. gigas* findings (Table 4.17; Chapter 4). However, the present tissue cadmium and lead concentrations were higher than *C. gigas* tissue concentrations in Hawai`iand other parts of the United States Other tissue contaminants were lower than United States oysters. National comparisons were limited by the low number of *T. chilensis* trace metal concentration studies (Table 6.9). The present tissue copper, manganese and zinc concentrations were higher than *T. chilensis* from more pristine sites in Marlborough, Nelson and Foveaux Strait, while the present tissue cadmium concentration (0.8-3.7 ppm) was much lower than these previous studies (3.3-47.9 ppm) but higher than Tasman Bay levels (formerly *Ostrea lutaria*: 0.12-7.9 ppm). Previous studies have suggested that *T. chilensis* contamination is unlikely sourced anthropogenically (Frew and Hunter 1995) and instead is due to the biological mechanisms (Perez-Diaz 2013). High tissue cadmium concentration was found in *T. chilensis* despite Foveaux Strait having low cadmium concentrations within the seawater, 0.02-0.06 ppm (Frew and Hunter 1995), and sediments 0.03-0.34 ppm (Frew et al. 1997). Conversely, historical sources of high cadmium levels in *T. chilensis* (formerly *Ostrea lutaria*: 0.12-7.9 ppm) and scallops, *Pecten novaezelandiae* (0.14-0.28 ppm), of Tasman Bay was suggested to be associated to anthropogenic sources such as aerial crop dusting using superphosphate fertiliser as well as potential sewage effluent discharge (Nielsen and Nathan 1975)..

Potential natural and anthropogenic sources of trace metals above local or global findings is indicated in the present study (Appendix 7.1). The *A. stutchburyi* inorganic arsenic concentration, which exceeded the level for human consumption at Saltwater Creek River during winter 2015 (Section 6.4.3) could potentially be sourced from arsenic-based chemical industries (e.g. timber), agriculture (fertilisers and pesticides) and earthquake-damaged structures. The tissue arsenic of *P. australis* and manganese of *P. australis* and *T. chilensis*from Banks Peninsula would likely be naturally sourced from volcanic sediment and the release of geothermal water input (e.g., hot water springs at Rāpaki that were mentioned by LPS, Chapter 5). Elevated copper concentrations in *P. australis* and *T. chilensis* could be due to sewage sludge, agricultural products (water treatment) or sheet material (housing).

Austrovenus stutchburyi contamination correlation findings

The correlation of sediment grain size with sediment contamination is particularly interesting given that the *A. stutchburyi* recruitment density correlation with sediment grain size followed the opposite pattern. Filter-feeding bivalves can accumulate metals by assimilating sediment-bound metals from solution and diet (Griscom and Fisher 2004), the former of which may include a contribution of sediment pore water in the case of soft bodied burrowers, whilst the latter may include sediment particles in the case of sediment-ingesting deposit feeders (Rainbow 2002). The relative importance of ingestion as a route of metal uptake has been compared quantitatively with uptake from the dissolved phase (including from pore water and from overlying water) and has been shown to account for high concentrations in bivalve tissues for a number of contaminant metals (Griscom and Fisher 2004). In the present study, concentrations of chrome, copper, lead, and zinc in *A. stutchburyi* tissue was positively correlated with sediment values, which may indicate available metals via pore water, given that *A. stutchburyi* is a soft-sediment dwelling bivalve, not a deposit feeder.

In the present study, the sediment copper, lead and zinc concentrations were significantly variable across sites, while tissue copper and zinc concentrations were uniform across sites. The former three metals are ubiquitous within urban systems, for instance in zinc run-off from roofing, copper-covered wires and stormwaters (Williamson and Wilcock 1994, Bolton-Ritchie and Lees 2012) as well as other similar anthropogenic sources (e.g. fertiliser; Table 7.1). Accumulation levels of copper and zinc may not vary because they are essential metals (Prasad 2013). The European cockle, *Cerastoderma edule*, showed an accumulation of tissue lead , while tissue copper and zinc concentrations were lower because they were biologically regulated (Cheggour et al. 2001). Estuaries act as sinks for terrestrial and freshwater contaminant inputs and sediment-bound metals can also be a source of contamination to aquatic inhabitants. For instance, sediment-associated contaminants can be a long-term source of toxic substances to biota occupying the receiving environment (Baker and Kravitz 1992).

Tissue *E. coli* concentrations correlated negatively with salinity, were significantly elevated during winter (Section 6.3.5) and exceeded guidelines, especially at low salinity sites (Section 6.4.3). Similarly, the maximum level of *A. stutchburyi* tissue enterococci was correlated with high winter rainfall (De Luca-Abbott et al. 2000), while an inverse relationship was found between salinity and faecal coliforms and *E. coli* (Goyal et al. 1977, Mallin et al. 2000). Within Christchurch, faecal water readings have exceeded guidelines during increased rain input in summer (Bolton-Ritchie 2012), and during stable weather (McMurtrie and Hewitt 2013). Furthermore, it was found that ruminant *E. coli* and enterococci that exceeded guidance level had travelled via river plume and were detected within shellfish tissue to a distance of 6 km offshore (Cornelisen et al. 2011).

Table 6.9. Trace metal concentrations in various species (ppm dry weight) in New Zealand, including this current study (bold) and various international studies. Cells are blank where there were no reported results.

Species	Area	Metal concentration									
		As	Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn	Reference
NZ clams, oysters, and mussels											
A. stutchburyi	Auckland estuaries		≤2.3			4-12			≤1.0	78-100	(Stewart 2006)
	Otago Harbour				1-44	3-60	2-12	5-35		40-118	(Peake et al. 2006)
	Canterbury	10.0-22.0	0.2-0.5			6.0-9.8				45.0-65.0	(Adkins and Marsden 2009)
		14.8-48.4	0.2-0.4	0.3-0.7	0.5-3.0	5.3-9.2	1.6-5.5	1.0-3.1	0.3-2.8	38.2-67.3	(Marsden et al. 2014)
	Canterbury	**15.0-45.4**	**0.1-0.6**	**0.6-1.6**	**0.6-3.4**	**3.7-9.2**	**8.8-30.5**	**2.2-5.1**	**0.2-1.8**	**49.5-105.5**	**Present study**
Paphies australis	Maketu, Rotorua	9.7-13.0	0.4-0.5		3.2-11	4.7-5.4		3.0-7.2	0.1-0.2	54-65	(Phillips et al. 2011)
	Canterbury	**8.9-14.2**	**0.1-0.2**	**0.6-1.2**	**0.9-1.3**	**4.4-7.9**	**70.6-188.0**	**0.6-1.0**	**0.7-1.5**	**34.6-59.2**	**Present study**
Tiostrea chilensis	Tasman Bay, Nelson		4.0-16.2			12.7-38.0	8.7-85.5			241.8-400.4	(McEntyre 1996)
	Oyster Bay, Marlborough		3.3-7.3			40.9-58.9	8.1-15.7			258.2-927.5	
	Foveaux Strait		21.2-47.9			6.9-30.1	2.0-4.8			140.9-423.6	
			5.9-34.9								(Frew et al. 1997)
	Canterbury	**8.6-17.0**	**0.8-3.7**	**0.3-0.5**	**0.5-1.3**	**44.2-256.3**	**21.5-37.5**	**0.4-0.9**	**0.4-1.7**	**58.5-1496.0**	**Present study**
Mytilus edulis aoteanus – blue mussel	Wellington	11.9-17.2	<1.0		5.1-15.8	10.7-18.3	9.7-21.6	6.0-10.3	3.2-30.5	201-311	(Anderlini 1992)
Perna canaliculus – green-lipped mussel	Maketu, Rotorua	7	0.5		11	3.9		8.1	0.5	67	(Phillips et al. 2011)
International clams, oysters, and mussels											
Cerastoderma edule, European cockle	Ria de Aveiro, EU	1.2-2.2	0.06-0.2		0.3-0.9	0.5-2.0		1.6-5.2	1.2-5.2	34.2-55.4	(Figueira et al. 2011)
	Morroco, Mediterranean		1.6-2.4			8.8-22.6			16.5-18.9	58.3-115.0	(Cheggour et al. 2001)
Chione sp. – clams	Altata-Ensenada del Pabellón lagoon, Mexico		1.3-3.8		0.4-1.5	8.3-11.8	13-69	3.3-13.0		25-1247	(Páez-Osuna et al. 1993b)
			1.7-3.5		1.0-3.0	33.0-57.7	16-80	8.9-11.1		64-1218	
	Navachiste Lagoon, Mexico		1.5	2.3	2.7	13.2	23.2	5.6		118	(Paez-Osuna et al. 1991)
Paphia undulata – surf clam	Gulf of Thailand, SE Asia		0.3-0.8		0.3-1.0	4.6-7.4		1.30-2.00	0.55-1.39	42.0-57.9	(Phillips and Muttarasin 1985)
Tellina sp. – clams	Altata-Ensenada del Pabellón lagoon, Mexico		2.9-8.7			29.4-54.7	10-43	1.2-6.5		64-1944	(Páez-Osuna et al. 1993b)
	Pago Bay, Guam	9.71-27.2	<0.08-0.1		<0.1-0.5	4.22-68.5	2.9-23.1	10.4-24.7	0.20-0.89	93.6-341	(Denton et al. 2006)
	Tanapag Lagoon, Saipan		0.2-0.4		4.8-10.6	14.7-1876		8.32-13.1	5.94-184	406-993	(Denton and Morrison 2009)
Mytilus edulis – blue mussel	East Looe Estuary, U.K.		2.3		2.5	9		2.6	45	113	(Bryan 1980)
	Tomales Bay, U.S.	5.5-6.8	4.3-5.5		1.1-3.2	4.9-8.0	24.7-54.0	3.8-6.6	0.42-0.99	65.3-116.7	(NOAA 1989a)
	San Fran. Bay, U.S.	4.6-8.5	5.9-6.6		1.7-2.4	5.4-9.3	29.7-65.3	3.6-4	0.73-.3.7	150	
	Tomales Bay, U.S.	7.8	4.9		2.1	6.3	24.5	3.8	0.45	107	(NOAA 2015)
	San Fran. Bay, U.S.	5.6-9.1	2.3-3.6		3.2-6.8	7.3-11.4	33.9-154	3.3-6	0.6-1.4	85.5-153	

6.4.5. Socio-cultural and ecological findings to better guide management

The socio-cultural values (previous chapter) alongside the ecological findings (current chapter) are discussed here towards better decision making within estuarine systems in Waitaha, Canterbury. The following environmental indicators or practices are discussed to provide better guidance towards management. They include holistic values, sediment and contamination (pollutants, sewerage/septic, food safety), salinity variability and land–to-sea practices.

Holistic values

In the present study's interviews, Local Practitioners and Specialists (LPS) and Recreational Participants (RP) shared that Waitaha estuarine systems have long-standing value to Tangata whenua and New Zealand Europeans and citizens. They are places of wellbeing, New Zealand cultural heritage, Mana whenua whakapapa and tūrangawaewae (e.g. Figure 5.1), tribal mahinga kai, commercial fishing, and family activities. These estuaries support an integral part of the cultural identity of New Zealanders (Thrush et al. 2013). New Zealander's ability and level of safety to fish, wade, and partake in recreational activities (swimming/walking/running) in these areas were important. Whakapapa and mahinga kai is the main axle upon which Ngāi Tahu identity with the natural environment revolves (Te Rūnanga o Ngāi Tahu, 2004).

"*Food is not just a resource for sustenance… Food needs to be understood as a wider cultural concept that interweaves complex Indigenous cultural and environmental relations, relations that Adelson (2000) constructs as the opportunity to experience 'being alive well'.*" (Panelli and Tipa 2009).

Similar to previous documents of cultural indicators, within this study environmental indicators include mahinga kai, indigenous flora and fauna, water flow and river to sea management (Tipa and Teirney 2003, Te Rūnanga o Ngāi Tahu 2004, EC 2011). The poorer scores given to environmental site and catchment by Ngāi Tahu (LPS and RP) compared to non-Ngāi Tahu, including New Zealand European and Māori (LPS and RP), highlighted the long-term degradation observed and experienced in their cultural-ecological practices. In this study environmental degradation and the decline or loss of shellfish has been observed by Local Practitioners and Specialists and supported by the sparse oyster densities of Koukourārata and Rāpaki and the cockles of Rāpaki. Low cockle abundance has been evident in previous surveys at Koukourārata pā (Voller 2003, Adkins 2012), but and this is the first oyster and cockle survey at Rāpaki. If mahinga kai are no longer present to harvest, the practices and knowledge associated with sustainable management are potentially undermined and the strong connection to a local place and its associated responsibilities to exercise kaitiakitanga may be weakened (McCarthy et al. 2014). In this study, cockles are not harvested by Ngāi Tahu in three of the four estuaries or by Recreational Participants (non-Ngāi Tahu) in two of the four estuaries due to poor cultural-safety values, poor food safety and issues of sustainability. Therefore, disconnection between tangata and whenua is created by poorer estuarine conditions.

Sediment and contaminants

The negative impact of sediment (especially silt) on shellfish was perceived by LPS andRP and represented as environmental concerns by kaitiaki (Mudunaivalu 2013). This same impact was reported in an assessment of the local ecological knowledge across New Zealand (Morrison et al. 2014b). Most sediment input enters estuaries during storm events, mostly in the form of fine silts and clays (Thrush et al. 2004) and has been observed at the estuaries studied here. It is therefore concerning that the climate projection for many regions, indicates that rainfall and storm frequency will be more intense (Inman and Jenkins 1999). Management will need to account for existing sediment composition, sediment-bound metals and prevention of additional input.

Sediment run-off and effects on shellfish were key indicators within the socio-cultural findings and ecological findings in this study. Areas of elevated silt composition, sediment contamination, and poor population structure (such as low recruitment) particularly require further attention by management. Stewart (2006) indicated that there is potential for cockle populations to collapse where populations are maintained by very low-level recruitment and if several years of poor recruitment or additional stress (e.g. anthropogenic impacts) are imposed. Ngāi Tahu members have long reported that the unreasonably large recreational bag limit was a concern as it results in over-harvesting of the cockles beds (Waitangi Tribunal 1992). Other shellfish studies in New Zealand have also reported that bag limits are too large and therefore are not sufficient management measures (Hartill et al. 2005, Stewart 2006, Adkins 2012). Management generally relies on local bag limits and closures, which alone are not sufficient, and should include minimum size limits and the management of anthropogenic activities (Hartill et al. 2005).

Based on their cultural environmental values, Ngāi Tahu gathered outside the areas of treated/untreated sewage/septic tanks and avoided sites of previous or continued treated sewage/septic tanks, and industrial discharge (e.g. from tanneries). In the past, industrial and municipal contaminant discharges to estuaries like the Avon-Heathcote, were more numerous, with the majority being untreated (e.g. from tanneries, timber and woollen mills) (Robertson et al. 2002). Some RP gathered shellfish from the Avon-Heathcote despite long standing shellfish warnings signs. This is a concern given the elevated concentration of tissue *E. coli* near sites where less experienced RP (<20 years) were observed gathering. In particular, Te Ihutai was compulsory acquired under the Public Works Acr (1928) as part of the Christchurch sewerage works development. There has subsequently been discharge of sewage (Tau et al. 1992) and following this, local iwi placed Te Ihutai (the reserve) under a rāhui due to discharge of human effluent, even after treatment (Boyd 2010). Water pollution (water quality, sediment run off/deposition, sewage and metals) and the associated effects on the estuary, mahinga kai and mauri, are factors that affect Māori environmental and cultural values (Harmsworth 1997). The present study found *A. stutchburyi* tissue *E. coli* concentrations exceeded safe shellfish consumption guidelines during summer and winter periods at the Saltwater Creek and Avon-Heathcote Estuaries (Section 6.4.2). Further education and health warning posts are required at sites that exceed contamination guidelines. As suggested by Jackson (2005), the protection of Indigenous cultural values protects a wider range of activities and values. The protection of current shellfish beds of cultural-significance is important to prevent further boundaries between local people and these highly-valued environments.

Salinity gradient

Harvesting locations differed between groups of varying experience and cultural affiliation. Both the Ngāi Tahu (LPS and RP) and long-term RP (non-Ngāi Tahu) usually gathered shellfish nearer marine input sites and during winter only used shellfish for bait. Conversely, the short-term RP (excluding Ngāi Tahu) harvested and fished for bottom-dwelling fish near low salinity input sites. This agreed with Mudunaivalu (2010), who reported that the Māori community conducted most shellfish harvesting in the summer months and very little if any in winter. This coincided with the shellfish data, where the pipi condition index (CI) was higher in summer than in winter and the cockle CI was associated with higher salinity and temperatures. Previous studies have found the *A. stutchburyi* CI increased with salinity within Canterbury estuaries (Marsden and Pilkington 1995, Adkins 2012), while the present study is the first to show elevated *A. stutchburyi* tissue *E. coli* concentrations associated with low salinity sites (Section 6.4.2). These findings support the necessity of localised and estuarine-tailored methodologies due to the variation in physico-chemical characteristics and sediment composition (amongst other parameters) (Chapman et al. 1998, Robertson et al. 2002). Evaluating the full scope of physico-chemical dynamics is limited by this study. The differences within socio-cultural interviews would benefit from participatory evaluations to fully understand cultural-based health guidelines towards better management (as conducted by Tipa and Nelson 2011). Given that all Ngāi Tahu interviewees in this study avoided food gathering from poor estuarine environments, but non-Ngāi Tahu harvesters did not, suggests that Ngāi Tahu values having stricter practices and protection from unsafe exposure. It is noted that the Māori cultural stream health measures utilised within the Cultural Health Index has been found to impose a stricter standard than quantitative scientific invertebrate methods (Harmsworth et al. 2011).

In contrast to the *A. stutchburyi* tissue findings, the sediment Metal Pollution Index (MPI_8) was elevated at Koukourārata pā and Heathcote, the two sites varied in salinity regime, but similarly had steep catchments with reported high sediment loads. Sediment contaminant concentration potentially affects the sustainability of *A. stutchburyi* (i.e. recruitment), which indicates that better understanding of this system is required. Monitoring the condition of an estuary is complicated by the high natural spatial and temporal variability associated with complex and dynamic estuarine environments (Pridmore et al. 1990). The stability of sandflat macro-invertebrate communities (such as *A. stutchburyi* in this study) is useful for long-term biological effects in estuaries (Turner et al. 1995). Further research is needed to resolve temporal and spatial variability in New Zealand estuaries (Robertson et al. 2002).

Catchment effect and restoration practices

Very few RP provided a score for the catchment compared with the LPS especially Ngāi Tahu, suggesting that the latter groups may be more concerned with catchment to sea connection and management. Within other catchment land-use research, land degradation resulting from changes in land use and/or climatic conditions is a concern not only to upland farmers but also to the users of water resources downstream (Valentin et al. 2008). Within the current LPS scores, highly intensive agricultural and urbanisation land uses were both associated with poorer site conditions. Within the scientific findings, the site condition was impacted by multiple landscape indices. For instance, the highest sediment Metal Pollution Index occurred at the head of estuaries at Heathcote and Koukourārata pā, sites that receive heavy sediment loads from mountain catchments of very low protective land cover (Section 6.4.4). Ecological damage to mahinga kai areas has been due to the management of surrounding land uses and water uses (Waitangi Tribunal 1995).

Mana whenua and shellfish ecologists agree that marine enhancement benefits certain estuaries. As discovered in these interviews, Mana whenua have practiced transplanting (‘moving of shellfish’) and re-seeding, as have LPS marine ecologists. The enhancement of marine resources is part of the responsibilities and obligations of iwi members, in accordance with kaitiakitanga (Best 1929), which included shellfish re-seeding and translocations, as also practiced by Ngāi Tahu iwi (Waitangi Tribunal 1987, Tau et al. 1992) as well as seeding of pipi and cockles near the stream mouth (Tau et al. 1992). The transplanting of cockles by ecologists and local iwi members was successful at Saltwater Creek but not Rāpaki (personal communications 2016, Adkins), and studies have found that the transfer of adult cockle stock may be the most promising technique for restoration in Canterbury (Marsden and Adkins 2010, Adkins 2012). In this study, Mana whenua harvesters shared site-specific conditions for transplanting cockles, one of the differences being across salinity and sediment composition gradients. Iwi ecological restoration knowledge would benefit local management. Expanding current populations could also increase shellfish capacity to benefit eco-services such as water quality (Coen and Luckenbach 2000, Bolam et al. 2002, Dame 2011, Kainamu 2011). Introducing shellfish (rather than transplanting individuals within estuaries) was not welcomed by all Rūnanga, therefore, local engagement is recommended. Additionally, LPS shared that site-restoration required full catchment management, so Mana whenua, New Zealand European LPS and the Council have been replanting the catchments and streams at these estuaries (Pers. Comm. and Chapter 5 Interviews).

The key objective of the Canterbury Water Management Strategy is to manage the environment ‘ki uta ki tai’ (Canterbury Water 2012). The measurements within the current study indicate that site conditions are linked to freshwater and terrestrial input, a result of catchment land-use and land-cover. This present study supports the advice by the New Zealand Ecological Society that estuaries should be provided for within the National Objectives Framework for Freshwater Management, rather than managed within the New Zealand coastal system. Additionally, the ethic of ki uta ki tai set out within the waterway objective of Environment Canterbury, further requires socio-cultural values to be protecting as its own set of values and knowledge.

6.4.6. Co-management and further recommendations

Indigenous people interviewed in this present study described the need for changing fishery practices to respond to declining fisheries, as well as the traditional systems that would benefit fishery. Enhancement of fishery as traditionally practiced within fishponds of Hawai`i (Chapter 3) and by re-seeding and transplanting as continued by Ngāi Tahu (Chapter 5) is a proactive approach towards shellfish sustainability, with successful outcomes found within ecological research (Marsden and Adkins 2010, Adkins 2012). Traditionally, māra mātaitai (seafood gardens/cultivation) in which shellfish husbandary included seeding of shellfish beds (Tau et al. 1992, Garven et al. 1997), habitat enhancement, tāikī (small enclosed seagood garden) (Anderson 1998, Williams 2016) had been a feature of the Māori economy for hundreds of years (Williams 2016). Additionally, allocation of shared resources within a tribe/subtribe functioned via the wakawaka system (Anderson 1998, Williams 2016), which in Canterbury, were “major divisions of land and sea, each of which could encompass numerous mahinga kai” (Anderson 1998). Shared by Rakiihia Tau, a kaumātua (elder) of Ngāi Tahu, “along our coast of South Brighton/Karorokaroro for the last four to five generations, seeding toheroa (large surf clam, *Paphies ventricova*) has taken place. These root stocks came from Kahuraki Point and Waiaka. Only recently Toheroa were again seeded locally” (Waitangi Tribunal 1987). The revitalisation or continuation of Ngāi Tahu methodologies were mentioned during this present study.

In New Zealand, holistic methods are not currently employed, although interest has been expressed (Tharme 2003). The exclusion of Indigenous ecological knowledge includes (but is not restricted to) the differences and dominance of Western science approaches (Flanagan and Laituri 2004, Gerhardinger et al. 2009) and inadequate frameworks for incorporating cultural values (Morgan 2006, Tipa and Teirney 2006, Harmsworth and Awatere 2013). Within the estuarine and marine environment, the Crown had developed and legislated customary area management tools, such as

Mātaitai and Taiāpure. The Taiāpure management tool in particular, which emerged in 1989 with legislative provisions provided in the Fisheries Act 1996, was found to be ineffective in its objectives to make "better provision for the recognition of rangatiratanga," as ultimately the Crown still holds the final decision-making power (Jackson 2011). Especially disempowering is the English common law-derived legal system that continues to restrict Indigenous Peoples from achieving their full aspirations (Morris and Ruru 2010). A more holistic approach that involving Mana whenua, Mātauranga Māori, and/or multiple local community members within taiāpure or mātaitai reserves has illustrated promising frameworks towards local management (Hepburn et al. 2010, Mudunaivalu 2013). This study agrees that the inclusion of both knowledge systems provides a more holistic approach to evaluating estuaries; the approaches complement each other towards better management. Further, this research recognises that environmental integrity is the ultimate baseline for estuarine management and that this would benefit from incorporating multiple knowledge systems (scientific, Indigenous, and long-term residents) towards better estuarine shellfish management.

6.4.7. Conclusion

This is the first study of the socio-cultural and ecological indices of shellfish across Canterbury estuaries, including shellfish species, habitat trace metal concentrations and *E. coli* contamination. Population and recruitment density were site-specific and influenced by multiple variables. Overall densities of *A. stutchburyi* were lower compared to the estimates by Adkins (2012), which likely reflected natural intertidal variability. For instance, mean *A. stutchburyi* densities were generally lower at low salinity sites, except Heathcote. The low density of *A. stutchburyi* at Rāpaki was likely due to environmental conditions that are favoured by *P. australis*, which was abundant. The relationship between bivalve and sediment characteristics likely explains this as both species are selective of the preferred sediment composition (Thrush et al. 2003, Anderson 2008), and Rāpaki sediment was coarser than other sites, which had higher *A. stutchburyi* densities. The *P. australis* population was predominantly made up of larger sizes, which is also due to natural intertidal variability (Hooker 1995, Mudunaivalu 2013). The *T. chilensis* population at the Rāpaki and Koukourārata rocky shores will not support long-term sustainability given the missing cohort sizes and extremely low densities.

Estuaries are viewed as sinks for terrestrial and anthropogenic materials; conversely, they could also be viewed as sources of contaminants to aquatic inhabitants. Within this study, silt was positively correlated with all sediment trace metal concentrations except arsenic. Similar to previous findings within estuaries of Auckland (Stewart 2006) and Canterbury (McConway 2008), *A. stutchburyi* recruitment was negatively associated to silt. Sediment is within the top five ecological issues for New Zealand estuaries (Stevens and Robertson 2012) as it is considered a contaminant to estuarine systems (Thrush et al. 2004). This concurs with socio-cultural values that found sediment and contaminants as top environmental issues in the current estuarine areas, in agreement with known Māori-cultural stressors to estuarine systems (Harmsworth 1997). Fine suspended sediment can transport sediment-bound contaminants and result in benthic smothering (Davies- Colley and Smith 2001b). Further understanding could improve managment at sites of elevated sediment input and contaminant input.

The integrity of environmental systems is vital for the identity, cultural aspirations and wellbeing of local communities. The cultural-ecological values of Ngāi Tahu were more often compromised than that of other cultural-groups (including the combined New Zealand European and New Zealand Māori/non-Ngāi Tahu) at each estuary. However, there were fewer New Zealand European Local Practitioners and Specialists (LPS) in this study and a greater number of recreational participants (RP) compared to Ngāi Tahu members. Previous studies have also found that cultural health of indicators are more strict than more quantitative measures such as macroinvertebrate indices (Harmsworth et al. 2011). Additionally, long-term residents who affiliated as New Zealand European, Māori and Ngāi Tahu, would like to gather, harvest and wade in these estuaries, but are restricted as the current conditions do not support these activities at all the areas studied. In particular, gathering cockles for consumption was open at the Rakahuri-Saltwater Creek and the Avon-Heathcote estuaries, however, the former site warns of toxic-algae, and the latter site has long-term warning signs due to industrial discharge and previous input of treated wastewater. Furthermore, this study found elevated cockle tissue contaminants at both estuaries and the effect of exposure of multiple contaminants on human wellbeing are not known (FSANZ 2015).

The effects of exposure to multiple contaminants on aquatic organisms (ANZECC and ARMCANZ 2000) is unknown. *Austrovenus stutchburyi* is a known tolerant bioindicator species (Peake et al. 2006, Adkins 2012) and a dominant bivalve species within estuarine systems (Larcombe 1971). However, in agreement previous findings (Stewart 2006, McConway 2008, Adkins 2012)the present study *A. stutchburyi* findings showed poor population structure at sites of elevated contamination. Long-term biological assessments are important components to monitoring because they measure the desired management goals for an ecosystem (ANZECC and ARMCANZ 2000). Estuarine condition and shellfish sustainability have been a long-standing problem in Waitaha, Canterbury, especially with regard to the values and concerns of Ngāi Tahu (Waitangi Tribunal 1987, Tau et al. 1992, Waitangi Tribunal 1992). Therefore, a more holistic approach towards management, that includes Tangata whenua cultural values at the beginning of decision making (Harmsworth and Awatere 2013), in particular Ngāi Tahu, and incorporates socio-cultural values and shellfish ecological indices, is recommended to improve management practices.

Chapter 7 Summary and general discussion

Across the world people have favoured and benefitted from coastal and estuarine areas. However, due to the activity and proximity of major human settlements estuaries rank among the most anthropogenically-impacted aquatic ecosystems on Earth (Kennish 2016). Chemical contamination, sewage and organic wastes, and human-induced sediment/particulate inputs within the top five stressors to estuarine ecosystems globally (Kennish et al. 2014) which can potentially affect estuarine condition, benthic communities and biodiversity (Kennish 1997, Edgar and Barrett 2002). Accumulation of contaminants in sediment and shellfish leads to aquatic toxicity and human health risks (U.S.FDA 1993, ANZECC and ARMCANZ 2000, Chase et al. 2001, FSANZ 2015). Globally, harvested benthic shellfish stocks have been declining (Castilla and Defeo 2001, Irwin 2004, Genelt-Yanovskiy et al. 2010).

Despite the fact that society is reliant on ecosystem integrity, our conventional evaluation of ecosystems does not incorporate local social mechanisms (Berkes et al. 2000a). Selection of indicators of estuarine characteristics should include the benthic and sedentary habitats, as well as social, cultural, ecological, and/or economical values (Gillespie and MacKenzie 1990, Roper et al. 1991, King et al. 2005). Increasingly, Traditional Ecological Knowledge (TEK) and Indigenous Knowledge (IK) is gaining recognition in fisheries research, marine conservation, and management (Mackinson and Nottestad 1998, Calamia 1999, Johannes 2002, FAO 2009, Gerhardinger et al. 2009). Indigenous People have witnessed a decline in local environments, systems the local tribe or community had traditionally managed. Recorded within interviews, and supported by literature, the identity and relationship of Kanaka Maoli and Tangata whenua/Māori to the land is genealogical and familial (Beamer 2005, Harmsworth and Awatere 2013). Symbolic values, self-identity, and sense of place are all inherently embedded within socio-ecological interaction and practices related to complex systems (Berkes 2012). Therefore, socio-cultural values are important components of the 'mountain to sea' (mauka makai, ki uta ki tai) environmental ethic in Hawai`i and Aotearoa New Zealand.

Within this study, estuarine shellfisheries were evaluated using multiple methods to understand the ecological and socio-cultural values in Hawai`i and New Zealand; values which are both legislated for within the United States and New Zealand (Section 1.2.1). This multiple methods approach builds on current knowledge for estuarine shellfish populations in Kāne`ohe Bay (O`ahu Island, Hawai`i) and Waitaha/Canterbury (South Island of Aotearoa New Zealand). The Kanaka Maoli and Ngai Tahu management philosophy, 'mauka makai' and 'ki uta ki tai', respectively ('from mountain/inland to the sea') forms the overarching principle of this study. Study areas were chosen to represent varying land-uses, fishery management (customary versus open-sites) and physico-chemical characteristics (e.g. salinity). Both the science and socio-cultural findings highlighted specific concerns regarding environmental integrity as presented together.

Mauka makai, ki uta ki tai; multiple values from land-to-sea

Chapter 2 Socio-cultural values

The estuarine environments were perceived by participants to be impacted by the surrounding catchment management (including land-use and land-cover) in both Hawai`i and Aotearoa New Zealand. This included loko i`a (traditional fishponds) and mātaitai (customary fishery reserves) in either area respectively. In the interviews conducted in this research, participants' top environmental indicator scores included sediment (e.g. mud/silt/run-off was perceived as poor), aquatic indices, water quality/clarity, sensory (e.g. smell), weather indices, contamination, and the interaction of people with place. Chemical contamination, sewage and organic waste and human-induced sediment/particulate inputs are within the top five stressors to estuarine ecosystems globally (Kennish et al. 2014).

Fishers in Kāne`ohe Bay favoured native fishery, but not necessarily shellfish. However, harvesing shellfish has been prohibited for over 30 years. Participants named 49 native fish, five native plants, three introduced fish, two introduced shellfish, and three introduced plants (Chapter 3). Shellfish were mentioned by more experienced participants, some who had observed mass harvesting during former open days and perceived their decline. Shellfish were also mentioned by those cultivating within loko i`a for the purpose of research/food security or commercial operation. Within this area, which is impacted by introduced species, the focus of native shellfishery was informative, however additional research on native fish and plant life is recommended to better align with socio-cultural values.

As expected, there is difficulty in expressing the socio-cultural values within a scientific forum, because the biophysical and cultural landscapes in which people interact are not neatly compartmentalised entities (Wilcock et al. 2013). The attempt to quantify the relative abundances of fishery resources within both Kāne`ohe Bay and Canterbury was not a useful measure, however, incorporating qualitative data provided for this flaw. Key themes emerged from the interviews that were indicative of changes in species abundance. These indicators included catch-per-unit-effort, shifting from native to invasive fishery, changes in fishing practices (including reduced commercial efforts or net bans) and laws to restrict gathering. Similar to Indigenous research, cultural values can be tangible, intangible and qualitative in nature (Jackson 2005). This study supports that the ecological knowledge of both Indigenous and non-Indigenous participants requires the inclusion of a qualitative approach.

There were similarities between the qualitative answers of Kānaka Maoli and Ngāi Tahu (LPS and RP) who ceased their practices (e.g., methods of fishing or target species) where there was perceived decline in the native fishery. Certain fishing protocols were more conservative than conventional management regulations or no longer occurred due to perceived impacts to environmental conditions. For instance, Ngāi Tahu (RP and LPS) collected shellfish at all estuaries except at the Avon-Heathcote and generally harvested from more saline sites, mixed-silt/sand substrates (i.e., "not sticky mud") and away from locations of any sewage input (treated or untreated). Many of New Zealand's estuaries and coastal sites have poor water quality, which has led to the restriction of human contact or consumption over long periods of time, e.g. Tauranga and Waihī Estuaries (Parliamentary Commissioner for the Environment NZ 2012). As concluded in previous research within Aotearoa, if mahinga kai are no longer present to harvest, the practices and knowledge associated with sustainable management are potentially undermined and the strong connection to a local place and its associated responsibilities to exercise kaitiakitanga may be weakened (McCarthy et al. 2014). Additionally, this study found that the poor condition of culturally important resources or the environment was a boundary to the traditional interaction of Mana whenua with their local tūrangawaewae. Disconnection from traditional practices will likely impact the adaptive process of Indigenous Knowledge (IK) and their respective practices, including kaitiakitanga.

In Canterbury, LPS, more experienced participants and Ngāi Tahu participants scored the environmental condition of sites and catchments poorly than did RP, less experienced and participants of other cultural affiliation (e.g. New Zealand European, Māori/non-Ngāi Tahu) and, these differences were statistically significant. This is suggestive of the impact of current environmental condition to Ngāi Tahu cultural-values as well as variation in the sensitivity of participants' activities. For instance, LPS took part in a wider range of activities and/or had higher interaction frequency than RP at these sites, including environmental monitoring (Figure 5.4, $p<0.05$). Additionally, a higher number of LPS favoured the current shellfish study species (cockles, pipi and oysters) compared to RP and especially distinguished between improved and degraded environmental conditions. Of particular concern was when New Zealand European Recreational Participants gave low scores to areas of leisure or wading as this is a favoured and important part of New Zealand culture.

The qualitative scores of more experienced Ngāi Tahu participants provided wider socio-political considerations that are rarely included within environmental monitoring. The findings in this study align with literature of ecosystem values by Māori, in which the loss of land (e.g., Te Ihutai was compulsory acquired under the Public Works Act (1928)), pollution (including sewage or other contaminants) affecting traditional areas of food gathering, and the depletion of natural resources degrade spiritual and cultural values for Māori (Harmsworth and Awatere 2013). Fundamentally, these are all destabilising factors on health and well-being, which are reflected within cultural values (Harmsworth and Awatere 2013). Cultural values are also explanations of knowledge or connections to a place, and establish responsibility to a geographical area or resource (Harmsworth 2005). Concerns over fishery decline and degraded environmental conditions in Canterbury and across Aotearoa have been voiced by numerous kaitiaki and local Māori for many decades (Waitangi Tribunal 1987, Harmsworth et al. 2011, Dick et al. 2012, McCarthy et al. 2014). It is suggested that the continued degradation of the environment has a cumulative impact upon Ngāi Tahu values and that the intergenerational experiences of Ngāi Tahu and more experienced participants are sensitive to these changes.

The current estuarine shellfish monitoring approach does not adequately protect the Indigenous environmental values in Waitaha Canterbury. As stated by one LPS, who was experienced within the science and cultural health index evaluation of a local estuary, "*the scientific measures do not reflect the cultural-based boundaries of these habitats.*" Cultural-based indicators included tangible and intangible metrics and would ultimately offer a stricter, more holistic view of the environment. This was similarly found within a study of the comparison of freshwater ecological integrity indices to cultural health indices (Harmsworth et al. 2011).

Chapter 3 Shellfish density and distribution

This was the first extensive survey of multiple shellfish across Kāne`ohe Bay, especially the edible clam, *T. palatum*, the once abundant Japanese littleneck clam fishery, *R. philippinarum*, and the biomonitors oyster species, *C. gigas*. The last extensive survey of *R. philippinarum* was conducted in the 1970s (Higgins 1969, Yap 1977) and a less-intensive survey of both clam species above in 2010 (Haws et al. 2014). Of these species, *C. gigas,* was found to be well-distributed across the northern (rural) to southern (urban) sector, while both clam species were of low abundances in the southern sector. Although the fishery has been closed for over 30 years, this present study did not see any indication of recovery of *R. philippinarum* or *T. palatam*.

Three endemic bivalves were surveyed across four Canterbury estuaries. The New Zealand littleneck clam, *Austrovenus stutchburyi*, was distributed across all soft-sediment sites with low density particularly at Rāpaki; the surf-clam pipi, *Paphies australis,* was only found in abundance at one site, Rāpaki; and the dredge oyster, *T. chilensis*, was found with low abundance at two rocky sites (Rāpaki and Koukourārata). The densities of *A. stutchburyi* and *P. australis* were lower than previously reported by Adkins (2012) and Mudunaivalu (2010) respectively, which was most likely due to differences in survey methods, particularly the intertidal zone location. *T. chilensis* distribution was sparse and without comparative survey, although participants reported higher past abundances. The current population structure indicated that *T. chilensis* was not surviving to the harvestable size class. Missing cohorts in a size frequency histogram may indicate a difference in survival of small and large individuals (Wenner 1988).

Shellfish decline seems evident of clam species in Hawai`i and oyster species in Aotearoa, which contrasted to the oyster species in Hawai`i and clams in Aotearoa. In addition, large intact dead *T. palatum* were observed in this study, as was previously noted within the 2010 survey (Haws et al. 2014), suggesting that larger sized clams are impacted by stressors. It is known that sediment run-off can negatively affect filter-feeding bivalves and in the past, silt run-off was also observed to smother *R. philippinarum* clams at Kāne`ohe Beach Park during high rainfall (Yap 1977). In Waitaha Canterbury, sediment smothering has been observed by Local Practitioners and Specialists (LPS) and via personal observation, as supported by highly variable silt composition measured at both rocky shore sites. In Canterbury, the *T. chilensis* population likely shares the same vulnerability as the Hawai`i benthic species, that is to freshwater and sediment stressors. These stressors could be worse due to the oysters' permanent fixture on their habitat. Clam restoration and culturing practices should also consider these factors. Fundamentally, the decline in fisheries can affect ecosystem functioning (Sandwell et al. 2009, Dame 2011) and the human social systems that is dependent upon the nature of resources, and their availability (Berkes 2009), and quality.

The current management regimes of bag-limits and site closures are not sufficient for the long-term sustainability of estuaries and do not protect against anthropogenic stressors. Additionally, bag limits were not adhered to by visitors to New Zealand (as personally observed and shared by local New Zealand European and Māori during interviews). Hartill et al. (2005) previously advocated for rotational-designed methods and size restrictions to compliment areas of closure and community-led management. Sites of long-term shellfish restrictions within this study did not necessarily result in increased shellfish abundance. Traditional fishing and sea farming/shellfish garden methods of Kanaka Maoli and Ngāi Tahu incorporated conservation, cooperation, gathering and preservation technologies towards management (Best 1929, Costa-Pierce 1987, Smith and Pai 1992, Beattie 1994, Dacker 1994, Anderson 1998, Poepoe et al. 2003).

It is recommended that marine enhancement is conducted alongside addressing catchment stressors as part of local community approaches in both Kāne`ohe Bay and Hawai`i, particularly in areas of native fishery. In Canterbury particularly, shellfish restoration and transplanting efforts conducted by Ngāi Tahu and scientists were shown in interviews to have been effective methods and can be found within scientific studies (Marsden and Adkins 2010, Adkins 2012). Given the long-term concerns at these sites, proactive approaches that combine both Indigenous and scientific knowledge systems is recommended in engagement with Mana whenua.

Chapter 4 Shellfish condition and contamination

The contaminant analysis of this study highlighted sediment contamination was elevated in Hawai`i while tissue contamination was eleveted in Aotearoa New Zealand. In Kāne`ohe Bay, sediment contamination was associated with catchment land use activities and stream input. The sediment contaminant Metal Pollution Index (MPI_8) was highest at the clam beds located near two stream mouths (He`eia and Kāne`ohe) and positively correlated with the catchment impervious surface area. Previous studies have found that suspended particular matter (SPM) in the Kāne`ohe Stream watershed controlled most stream trace metal transport (De Carlo et al. 2004) and these two streams are major contributors of total stream discharge into Kāne`ohe Bay (USAEC 1978). These results suggest that clam bed metal concentrations are directly influenced by the proximity to stream input in He`eia and Kāne`ohe Bay. Sediments in particular can act as a contaminant source to benthic organisms and have negative impacts (Jin et al. 2004), with coastal sites in Hawai`i vulnerable to the deposition of land-derived sediments, nutrients and pollutants transported from watersheds to the ocean (Rodgers et al. 2012). In addition, clam bed sediment metal concentrations had exceeded the aquatic toxicity guidelines, requiring further investigation by local agencies.

C. gigas was a useful indicator of environmental condition in Kāne`ohe Bay. *C. gigas* density, condition index (CI) and tissue contamination were indicative of varying environmental conditions. For example, *C. gigas* density and CI were negatively associated with tissue arsenic concentration, which was higher than previous *C. gigas* findings in the bay and in the United States (Table 4.18, Chapter 4). Tissue arsenic was particularly elevated at He`eia loko i`a, where the CI was poorest. Elevated arsenic coincides with the extensive restoration efforts of traditional Hawaiian agricultural-aquaculture systems, as the metal is likely released from historical extensive irrigated pond field systems and agriculture in Kāne`ohe, Kahalu`u, and He`eia ahupua`a (Handy et al. 1972, Kelly 1975, 1976, Rosendahl 1976). Studies in Hawai`i have found that previously used agricultural arsenic can provide sources of elevated contamination today (Cutler et al. 2013).

In Waitaha Canterbury, *A. stutchburyi* tissue MPI_8 was highest at a low salinity sites, including catchments with urban and intense agricultural land-uses. These sites had also exceeded the food safety consumption standard for tissue *E. coli* levels during this study. Additionally, the *A. stutchburyi* condition index (CI) and population density were negatively correlated with tissue MPI_8 and tissue *E. coli* concentrations. This former finding concurs with previous studies in Canterbury in which *A. stutchburyi* CI may indicate tissue contaminant burdens (Marsden et al. 2014). Similarly, *Crassostrea edule* CI was also suggested to indicate underlying trace metal body at sites of treated effluent input (Anajjar et al. 2008). Adkins and Marsden (2009) suggested that tissue contaminants may explain differences in *A. stutchburyi* population characteristics, depending on the influence to reproduction and recruitment. Repeated elevation of tissue *E. coli*, and a one-off elevation of tissue inorganic arsenic, is of concern where people were observed to harvest from these sites. Additionally, Canterbury estuaries were also at risk from raw sewage contamination due to earthquake damage to infrastructure that occurred in September 2010, February 2011, and June 2011. Public notices and further replication of these variables is advised. These site-specific variables (salinity and land-use) and shellfish indicators would provide useful for monitoring purposes, given that tissue *E. coli* is not a regular measure of current environmental monitoring.

Given that Hawai`i and New Zealand have experienced more recent industrialisation periods than other larger countries (such as the mainland Unites States and the United Kingdom), it is concerning that some of the contamination levels found in this research have exceeded either food safety consumption guidelines or aquatic toxicity guidelines, particularly those that were comparable with global values. For instance, *A. stutchburyi* tissue arsenic were higher than global clams and mussel species, and along with *T. chilensis*, arsenic concentrations were higher than the *C. gigas* concentrations in O`ahu. Elevated sediment contaminant sites (Koukourārata pā and Heathcote) were located near the head of estuaries, had intensive land uses (e.g. agriculture, forestry, industry) and reportedly large sediment loads during storm events (Section 6.4.1.). These site commonalities could be used to inform harvesting or restoration practices. Further scientific monitoring over time of anthropogenic stressors and their effects to ecological, social and cultural values will be critical.

Limitations and future recommendations

The effect of multiple contaminants to aquatic life is not yet known (FSANZ 2015), a fact to which this current study draws attention. Field ecological investigations are difficult but necessary because there are so many variables that may impact aquatic life that cannot be resolved in the laboratory. It is suggested that multiple stressors and catchment landscapes should be considered when managing shellfish areas as well as the potential placement and/or enhancement of marine reserves (e.g. transplanting) efforts. Recommendations for future research include the long-term effects of multiple contaminant exposure to benthic shellfish populations. Urban rivers act as a medium transferring a variety of contaminants (Glińska-Lewczuk et al. 2016) to which estuaries and coastal zones near large urban rivers are exposed (Chase et al. 2001).

This study recognises the land as a source of anthropogenic stressors, particularly to benthic shellfish and habitats compared to oysters on vertical structures that were not directly influenced by stream input (e.g. urban piers versus rural piers and any walls). Extensive restoration efforts were occurring in Hawai`i that may aid in reducing anthropogenic input and extensive efforts towards lo`i kalo restoration is underway in Kāne`ohe Bay. Recent research in Palau has shown that taro fields have the capacity to trap up to 90% of sediments, and suggest taro fields mitigate the negative impacts of soil runoff on receiving coral reef habitats (Koshiba et al. 2013). Long-term studies of the current elevated metals could provide further understanding of this process.

This study agrees with social-science research that local community management and Indigenous People should be included in environmental management decision making (Jackson 2005, Gerhardinger et al. 2009, Mudunaivalu 2013, McCarthy et al. 2014). Both Kāne`ohe Bay and Waitaha Canterbury estuaries currently benefit from 'ground-up' efforts of local communities. Local fisher knowledge is an essential means of achieving a broader and more diverse knowledge basis for Marine Protection Areas (Gerhardinger et al. 2009) and if ignored may place fishery resources at risk or unnessarily compromise the welfare of fishers (Johannes et al. 2000). Although local ecological knowledge and traditional practices are critical to resource management (Flanagan and Laituri 2004), they are not currently included in the decision making process (Tipa and Teirney 2003, Flanagan and Laituri 2004, Jackson 2005). This study could be improved by the guidance of Tipa and Nelson (2011), who utilised participatory planning and scoring towards understanding how river flows affect Tangata whenua meanings and associations (or values). This study leans towards progressing beyond descriptions of how indigenous and local communities value their estuaries to an understanding of how changed environmental conditions can affect these values. For instance, in Kāne`ohe Bay low site conditions were associated with water diversion, which has restricted stream input and flow, resulting in less abundant aquatic life. In Canterbury, an increase in intensive farming has been associated with degraded sediment conditions, poor sensory indicators (smells) and poor shellfish condition. A participatory approach would therefore provide a framework towards site-specific management that is translated to environmental management authorities.

Lastly, the statistical evaluation of this study was limited by the current landscape score and the influence of landscape-to-site comparison. The non-parametric correlation analysis of Landscape Development Intensity (LDI) index is useful for multi-scale approach assessments of environmental condition (Margriter 2011); however, more robust methods, including Pearson correlation (King et al. 2005, Galbraith and Burns 2007), are recommended. Additionally, it is recommended that ordination methods are investigated to better analyse the effects of multiple environmental factors on individual or multiple species. Also, the current LDI coefficients utilise a predetermined set of land use/land cover classes from the United States, which would benefit from grounding in localised investigations.

Conclusion

This research benefitted from utilising a multiple method and mixed-methods approach (quantitative/qualitative). The role of socio-cultural values, especially Indigenous knowledge, is so often compared and integrated with scientific findings. This research does not recommend integration, and where it is necessary, socio-cultural values research should stand alone to better protect these values. Where multiple values are concerned, the combination of sets of values (as evaluated within their respective epistemology) is recommended.

It is concluded that infaunal benthic shellfish in Kāne`ohe Bay were more impacted by anthropogenic conditions than the Pacific oysters that were attached to vertical structures. This was particularly true for structures that did not receive direct freshwater and the associated sediment input (piers rather than fishpond/loko i`a walls). In contrast, the oyster species in Waitaha Canterbury were sparse, and were fixed to rocky-shore habitats that received varying silt deposition. The condition index and density of Pacific oyster in Kāne`ohe Bay and the littleneck clam in Waitaha reflected environmental condition, and are suggested as useful biomonitors. The exceeding contaminant concentrations require further investigation in both locations.

Both Kānaka Maoli and Ngāi Tahu fishery practices responded to perceived declines in the native fishery. Socio-cultural indicators and management practices could inform best practices within these local environments. Environmental degradation and land-use managemnet impact the Indigenous fisheries practices in both locations. The values of Ngāi Tahu were compromised more often than those of non-Ngāi Tahu, due to the impacts of political and environmental degradation to estuarine sites and resources over time. Environmental indicators and condition were provided within the qualitative analysis. It is recommended that socio-cultural knowledge be incorporated within the management of environmental condition. Lastly, the present ecological and socio-cultural findings supported that estuarine management needs to recognise estuarine systems as receivers of freshwater and terrestrial systems.

Appendices

Chapter 2 Appendices

Appendix 2.1. Questionnaire forms for Local Practitioners and Specialists (LPS).

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

UC College of Science

School of Biological Sciences

Tel: (03) 364 2500, Fax: + 64 364 2590

Email: biology@canterbury.ac.nz

Location:

Date and time:

Project title: Natural resource management of the fishery

Questionnaire for local practitioners, stewards, managers, authority, long-term residents group participants

Name/anonymous:

Ethnicity:

Cultural affiliation(s):

Sex: Female/Male Age: >18-20, 21-30 ,31-40, 41-50, 51-60, 61-70,71-80, 81-90, 91+

Your role in the Group/Organisation:

Number of years in the role:

Location of Fishery Area:

Suburb:

SITE INFORMATION

1. Is this site valued as an area that was used in traditional / non-traditional / other historical uses (e.g. traditional fishery?) Other: ____
2. Today, is this a site of cultural use? YES/NO or Other ___________________________
3. How often do you visit this site? ____

4. Have you done any of these activities here (when was the most recent account:_______)?

☐ Collect living animal/plant/other_________________ ☐ to eat, bait, material, other____________

☐ Collect non-living shells/stones/plant/other__________ ☐ to eat, bait, material, other____________

☐ (Leisure) walk/run/swim/bathe/sit and be outside/boat, other _______________________________

☐ Other or Extra notes: ____

5. What is the best time(s) of the year for this activity (above)?

____

6. What part of this site do you do this activity? (E.g. mid-tide, low-tide, in the water at low tide…)

____

7. How far do you go/walk to your site (metres)? ___________________________________

8. How long do you spend here (per day) doing this activity? __________________________

FISHERY AND ENVIRONMENTAL HEALTH

9. What living plants/animals/others do you favour as a resource (bait, food, other)? Please list these:

____

____

____

10. Have these changed in abundance in the last 30 years? YES/NO

NOTE: If there are recollections more recent, 10/20 years, add to the bottom of the questionnaire.

a. If YES, what abundance remains today compared to the past 30 years?

Species name:	**% of the past species abundance that is available today**
1.	10%, 25%, 50%, 75%, 100% n/a
2.	10%, 25%, 50%, 75%, 100% n/a
3.	10%, 25%, 50%, 75%, 100% n/a
4.	10%, 25%, 50%, 75%, 100% n/a
5.	10%, 25%, 50%, 75%, 100% n/a
6.	10%, 25%, 50%, 75%, 100% n/a
7.	10%, 25%, 50%, 75%, 100% n/a
8.	10%, 25%, 50%, 75%, 100% n/a

b. Are there any other species gathered in the past that are not available today?

____

____

11. How would you describe the general condition of the site where you do the above activity?

____

CONDITION SCALE:	1	2	3	4
	Poor	Fair	Good	Excellent

12. How would you describe the general condition of the wider catchment area?

____

13. Would you return to the site in future? YES/NO, please explain:

____

____

14. What are the main environmental indicators that signal good/poor conditions for gathering natural resources, especially food and bait?

Good Indicators	**Poor Indicators**

MANAGEMENT

15. What main changes (if any) have you seen in this area over time? (time reference ________)

- ☐ Catchment land use
- ☐ Water quality
- ☐ Water Flow
- ☐ Sediment
- ☐ Other if YES, what are they: ____

If YES to any of the above, please explain:

____

____

____

16. Do you know what the current management is here? YES/NO

If YES, what are the current regulations:____

____

17. If YES, do you think the current management is effective? YES/NO

Please explain: ____

____

18. What are the geographical boundaries of this management area?

____

____

19. Is this management boundary the same as what was in the past? YES/NO

If NO, please explain: (perhaps change in physical managed area, or change in social community)

____

____

DO YOU HAVE ANY FURTHER COMMENTS?

____

____

____

____

____

From question 10 - if required: What abundance remains today compared to the past 10/20 (CHOOSE ONE) years?

Species name:	**% of the past species abundance that is available today**
1.	10%, 25%, 50%, 75%, 100% n/a
2.	10%, 25%, 50%, 75%, 100% n/a
3.	10%, 25%, 50%, 75%, 100% n/a
4.	10%, 25%, 50%, 75%, 100% n/a
5.	10%, 25%, 50%, 75%, 100% n/a
6.	10%, 25%, 50%, 75%, 100% n/a
7.	10%, 25%, 50%, 75%, 100% n/a
8.	10%, 25%, 50%, 75%, 100% n/a

NGĀ MIHI NUI, THANK YOU VERY MUCH

END OF QUESTIONAIRE

Appendix 2.2. Questionnaire forms for the Recreational Participants (RP).

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

UC College of Science

School of Biological Sciences

Tel: (03) 364 2500, Fax: + 64 364 2590

Email: biology@canterbury.ac.nz

Location:

Date and time:

Project title: Natural resource management of the fishery

Questionnaire for recreational group participants

Name /anonymous:

Ethnicity:

Cultural affiliation(s):

Sex: Female/Male   Age: <20 21-30 31-40 41-50 51-60 61-70 71-80 81-90 91-100

Your residence:

SITE INFORMATION

1. Why are you here today? To:

☐ Collect living animal/plant/other__________________ ☐ to eat, bait, material, other______________

☐ Collect non-living shells/stones/plant/other___________ ☐ to eat, bait, material, other______________

☐ (Leisure) walk/run/swim/bathe/sit and be outside/boat, other _________________________________

☐ Other or Extra notes: ____

2. How often do you visit this site? ____

3. What is the best time of the year for this activity (above)? ________________________________

4. What part of this site do you do this activity? ____

5. How far do you go/walk to your site (metres)?____

6. How long do you spend here (per day)? ____

FISHERY AND ENVIRONMENTAL HEALTH

7. What living plants/animals/others do you favour as resource (bait, food…)? Please list these:

____

____

8. In the last 30 years, have these changed in abundance? YES/NO

NOTE: If there are recollections more recent, 10/20 years, add to the bottom of the questionnaire.

a. If YES, what abundance remains today compared to the past 30 years?

Species name:	**% of the past species abundance that is available today**
1.	10%, 25%, 50%, 75%, 100% n/a
2.	10%, 25%, 50%, 75%, 100% n/a
3.	10%, 25%, 50%, 75%, 100% n/a
4.	10%, 25%, 50%, 75%, 100% n/a

b. Are there any other species gathered in the past that are not available today?

____

____

9. How would you describe the general condition of the site where you do the above activity?

____

CONDITION SCALE:	1	2	3	4
	Poor	Fair	Good	Excellent

10. How would you describe the general condition of the wider catchment area?

____

11. Would you return to the site in future? YES/NO, please explain:

____

____

12. What are the main environmental indicators that signal good/poor waterway health for gathering natural resources, especially food and bait?

Good Indicators	**Poor Indicators**

MANAGEMENT

13. What (if any) main changes you have seen in this area over time? (time reference ________)

- ☐ Catchment land use Water Flow
- ☐ Sediment Water quality
- ☐ Other if YES, what are they:

____

If YES to any of the above, please explain:

____

____

14. Do you know what the current management is here? YES/NO
15. If YES, what are the current regulations: ____
16. If YES, think the current management is effective? YES/NO

Please explain: ____

17. What are the geographical boundaries of this management area?

____

____

18. Is this management boundary the same as what was in the past? YES/NO

If NO, please explain: (perhaps change in physical managed area, or change in social community)

____

____

DO YOU HAVE ANY FURTHER COMMENTS?

____

____

<u>Q8. If required:</u> What abundance remains today compared to the past 10/20 (CHOOSE ONE) years?

Species name:	**% of the past species abundance that is available today**
1.	10%, 25%, 50%, 75%, 100% n/a
2.	10%, 25%, 50%, 75%, 100% n/a
3.	10%, 25%, 50%, 75%, 100% n/a
4.	10%, 25%, 50%, 75%, 100% n/a

NGĀ MIHI NUI, MAHALO, THANK YOU VERY MUCH.

END OF QUESTIONAIRE

Appendix 2.3. The 1978 and 2005 land use/land cover (LU/LC) classifications in Hawai`i, and their associated LDI coefficients calculated in 2012 (Jensen 2014). A further calculation in 2014 during this current study (in bold) was also done because of the different 2005 C-CAP impervious surface layer.

1978 LU/LC	2005 LU/LC	LDI
	Unclassified; 0 Background; **1 Unclassified** E.g. cloud cover	
4 Forest Land **3 Rangelands**	**Forest Land** **Scrub Land** **Grassland** **8 Grassland/Herbaceous***	1.00 1.42
5 Water **6 Wetland**	**Water and Submerged Lands** **Palustrine Wetlands** **Estuarine Wetlands**	1.00 1.26 1.65
2 Agricultural Land	**Agricultural Land** **7 Pasture*** **6 Cultivated Land** Includes herbaceous (cropland) and woody cultivated lands.	 5.09 3.91
1 Urban or Built-up land 11 Residential 17 Other urban or built-up land **7 Barren Land** (semi-utilised)	**Developed** **5 Open Spaces Developed** Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces < 20 % of total cover. **Barren Land**	5.09 (low density residential, and low density recreational/ open space, and pasture) 4.19
1 Urban or Built-up land 12 Commercial and services 13 Industrial 14 Transportation, communications and utilities 15 Industrial and commercial complexes 16 Mixed urban/built-up land	**Developed** **2 Impervious Surfaces (includes low/medium/high intensity developed (2,3,4) levels)**	Intensity High: 8.98 Low: 7.72 **2014- Impervious Surfaces (includes urban or built-up land): 8.35**

Appendix 2.4. The 2012 New Zealand land use land cover (LU/LC) classification and associated LDI coefficients calculated in this current study.

2012 LU/LC	LDI
47-48 Flax, fern land	1.00
52 Manuka/Kanuka	1.00
54, 68 Broadleaved & indigenous forests	1.00
55 Sub-alpine shrubland	1.00
58, 80, 81 NZ scrub	1.00
7 Sand or gravel	1.00
14 Permanent snow/ice	1.00
16 Gravel or rock	1.42
15 Alpine grass/herb	1.42
43 Tall tussock grassland	1.42
45 Herbaceous fw veg.	1.42
46 Herbaceous mw veg.	1.42
Gorse/broom: 56, 64, 68, 71 Mixed exotic, harvested forest, cleared indigenous	1.58
20 Lake or pond	1.00
21 River	1.00
22 Estuarine	1.65
70 Mangrove	1.42
30 Short-rotation cropland	3.91
33 Orchards, vineyards, other perennial crops	3.91
40 High producing exotic grassland (intensive grazing)	5.09
41 Low producing grassland	4.50
44 Depleted grass/bare	4.50
2 Urban parkland/open space	5.09
6 Surface mines or dump (bare)	4.64
12 Landslide (bare)	4.19
1 Build-up area (settlement), 5 Transport infrastructure	8.35

Appendix 2.5. Trace metal recovery, limit of detection, and percentage difference between duplicate samples

Trace metal recovery (±S.E.) of the Certified Reference Material (CRM) in (A) Kāne`ohe Bay, O`ahu and (B) Canterbury estuaries. The CRM included (Mussel) mussel tissue (NIST 2796) and (Sediment) marine sediment (NIST 2702) from the National Institute of Standards and Technology (NIST 2008, 2012), and (Fish) fish tissue (DORM-4) from the National Research Council Canada (NRCC 2012).

SCR certified concentration (dry weight mg/kg)										
	Cr	**Mn**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Cd**	**Hg**	**Pb**
Mussel	0.50	33.00	0.61	0.93	4.02	137	13.3	0.82	0.061	1.19
Fish	1.87	3.17	0.25	1.34	15.70	51.60	6.87	0.30	0.41	0.40
Sediment	352	1757	27.76	75.40	117.70	485.3	45.3	0.817	0.447	132.80
(A) Kāne`ohe Bay samples: CRM Recovery percentage ±S.E.										
	Cr	**Mn**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Cd**	**Hg**	**Pb**
Mussel (n=2)	69.08 ±3.97	126.82 ±5.89	114.91 ±2.69	88.45 ±3.74	102.55 ±6.11	114.17 ±1.33	138.71 ±4.52	113.16 ±3.18	No value	99.83 ±7.50
Sediment (n=2)	74.49 ±4.14	105.11 ±5.25	84.06 ±8.57	64.14 ±3.35	89.58 ±1.93	101.96 ±8.23	97.07 ±5.29	106.83 ±0.62	No value	114.64 ±26.71
(B) Canterbury samples: CRM Recovery percentage ±S.E.										
	Cr	**Mn**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Cd**	**Hg**	**Pb**
Mussel (n=7)	78.38 ±9.37	106.30 ±5.87	87.61 ±5.84	70.38 ±4.57	78.15 ±5.50	84.69 ±4.23	107.49 ±6.33	74.17 ±13.24	62.20 ±18.58	69.52 ±9.88
Fish (n=3)	69.67 ±6.66	87.18 ±5.33	78.61 ±5.55	73.38 ±6.70	88.42 ±9.83	85.49 ±5.79	95.63 ±5.94	85.40 ±4.04	28.74 ±22.68	44.27 ±19.96
Sediment (n=7)	74.30 ±2.70	96.35 ±1.93	85.17 ±3.45	74.24 ±2.62	86.68 ±2.8	85.80 ±2.82	86.83 ±2.56	103.95 ±2.42	84.42 ±16.41	99.10 ±7.52

*The fish tissue (DORM-4) has been found to be unsuitable for lead in an interlaboratory comparison (Ashoka et al. 2009). The mercury results were variable and problematic, and excluded from the results analysis.

The limit of detection (LOD) for the ICP-MS instrument (I) and blank (B) values in ppm from sediment and shellfish tissue samples from Kāne`ohe Bay and Canterbury.

Area	Kāne`ohe Bay				Canterbury			
Sample	Sediment		Tissue		Sediment		Tissue	
Element	LOD (I)	LOD (B)	LOD (I)	LOD (B)	LOD (I)	LOD (B)	LOD (I)	LOD (B)
Cr	0.41	0.14	0.26	0.05	0.41	0.14	0.25	0.29
Mn	0.42	0.36	0.25	0.05	0.42	0.36	0.25	0.03
Co	0.40	<0.01	0.26	<0.01	0.40	<0.01	0.25	<0.01
Ni	0.41	0.02	0.25	0.01	0.41	0.02	0.25	<0.01
Cu	0.41	0.13	0.26	0.31	0.41	0.13	0.25	0.09
Zn	0.65	0.20	0.32	1.21	0.65	0.20	0.35	1.37
As	0.44	0.04	0.24	0.02	0.44	0.04	0.26	0.07
Cd	0.41	<0.01	0.25	<0.01	0.41	<0.01	0.25	<0.01
Pb	0.42	0.04	0.26	<0.01	0.42	0.04	0.24	4.56

The duplicate differences in percentage for sediment samples from Kāne`ohe Bay and Canterbury. The tissue were not duplicates because they were invidual shellfish samples.

Area	**Kāne`ohe Bay**	**Canterbury**
Element	Sediment	Sediment
Cr	19.9-22.2	0.8-17.6
Mn	6.7-12.5	0.8-6.1
Co	11.3-38.1	0.2-6.9
Ni	19.5-24.0	0.2-6.4
Cu	24.4-29.3	0.8-11.0
Zn	12.3-26.4	0.8-6.6
As	46.1-52.1	0.2-8.5
Cd	5.5-6.7	1.8-10.0
Pb	2.1-9.4	0.1-12.1

Chapter 4 Appendices

Appendix 4.1. Global Position System (GPS) for the shellfish study sites listed in north to south for the respective clam and oyster study sites in Kāne`ohe Bay, O`ahu, Hawai`i.

		GPS Coordinates	
Sites	Transect line	N	W
Clam Bed Sites			
HSP	1	2144041	15780882
	2	2144033	15780884
	3	2144029	15780881
H	1	2143114	15780611
	2	2143107	15780612
	3	2143099	15780602
KBP	1	2141248	15778458
	2	2141254	15778458
	3	2141250	15778467
W	1	2141179	15778311
	2	2141175	15778304
	3	2141176	15778293
YWCA	1	2141180	15777834
	2	2141186	15777824
	3	2141185	15777809
Oyster Sites			
MLI	Wall	2150738	15784998
WP	Pier	2149289	15784706
HLI	Wall	2143593	15780536
LP	Pier	2142967	15779195
M	Wall	2143173	15778932
KP	Pier	2141383	15778575
WLI	Wall	2141165	15778273

Appendix 4.2. The correlation between clam species density and sediment composition, with significant values in bold.

	T. palatum	*L. obliquilineata*	*C. bella*	*T. philippinarum*	*L. hieroglyphica*	>2mm	>1mm	>500μm	>250μm	>125μm	>63μm	<63μm
T. palatum	1.00											
L. obliquilineata	0.06	1.00										
C. bella	-0.44	-0.38	1.00									
T. philippinarum	**0.53**	**-0.54**	0.33	1.00								
L. hieroglyphica	**-0.56**	-0.07	**0.53**	-0.10	1.00							
>2mm	0.01	-0.49	**0.53**	**0.55**	-0.10	1.00						
>1mm	-0.11	-0.39	0.38	0.27	0.13	0.44	1.00					
>500μm	-0.14	-0.37	0.10	0.20	0.34	0.32	**0.75**	1.00				
>250μm	0.01	-0.47	0.13	0.43	0.26	0.36	**0.51**	**0.85**	1.00			
>125μm	0.06	**0.64**	**-0.62**	**-0.59**	-0.12	**-0.80**	**-0.59**	-0.40	-0.31	1.00		
>63μm	-0.13	**0.59**	**-0.53**	**-0.68**	0.03	**-0.83**	-0.39	-0.30	-0.43	**0.86**	1.00	
<63μm	-0.14	0.49	-0.27	**-0.62**	0.20	**-0.69**	0.05	-0.06	-0.38	**0.52**	**0.79**	1.00

Appendix 4.3. The correlation between clam species density, abiotic value, landscape development, and sediment trace metal concentration. Significant values in bold.

Abbreviations are: (*T.p.*) *T.palatum*, (*L.o.*) *L. obliquenata*, (*C.b.*) *C.bella* , (*T.ph.*) *T.philippinarum* , and (*L.h.*) *L.hieroglyphica*, temperature (temp), salinity (sal), dissolved oxygen (DO), pore water (PW %), total volatile solids (TVS %), landscape development intensity (LDI), impervious surface area (Imp. Surf. %), and the marine pollution index (MPI_8).

Variables	T.p.	L.o.	C.b.	*T.ph.*	*L.h.*	PW	TVS	Temp (°C)	Sal (ppt)	DO (mg/L)	pH	LDI	Imp. Surf.	Cr	Mn	Co	Ni	Cu	Zn	As	Cd	Pb	MPI_8
T.p.	1.00																						
L.o.	0.05	1.00																					
C.b.	-0.38	-0.06	1.00																				
T.ph.	**0.66**	-0.25	-0.24	1.00																			
L.h.	-0.02	-0.11	0.41	-0.11	1.00																		
PW	-0.09	0.33	-0.26	**-0.49**	0.07	1.00																	
TVS	-0.12	-0.45	-0.03	-0.11	0.21	0.22	1.00																
Temp (°C)	**-0.62**	0.35	0.38	**-0.72**	-0.21	0.30	-0.11	1.00															
Sal (ppt)	-0.33	0.24	**0.80**	-0.35	0.37	0.06	0.00	0.44	1.00														
DO (mg/L)	-0.02	-0.32	0.11	**0.55**	-0.35	**-0.64**	-0.23	0.02	-0.18	1.00													
pH	-0.20	0.39	0.45	-0.22	0.23	0.08	-0.16	**0.48**	**0.66**	0.02	1.00												
LDI	-0.32	-0.32	**0.68**	0.00	0.33	-0.24	0.13	0.02	**0.71**	0.23	0.34	1.00											
Imp. Surf	0.04	-0.41	**0.45**	0.36	0.33	-0.39	0.13	**-0.47**	0.41	0.26	0.10	**0.89**	1.00										
Cr	0.26	**-0.66**	-0.09	**0.75**	n.v.	**-0.67**	0.13	**-0.54**	-0.38	**0.75**	-0.29	0.33	**0.69**	1.00									
Mn	-0.23	**-0.53**	-0.29	0.12	n.v.	-0.08	0.37	-0.45	**-0.65**	0.17	**-0.58**	-0.18	-0.03	**0.54**	1.00								
Co	0.09	**-0.71**	0.09	**0.67**	n.v.	**-0.56**	0.27	-0.41	-0.25	**0.80**	-0.22	**0.50**	**0.73**	**0.94**	**0.55**	1.00							
Ni	0.19	**-0.72**	0.03	**0.75**	n.v.	**-0.68**	0.24	**-0.51**	-0.33	**0.81**	-0.30	0.46	**0.77**	**0.96**	**0.51**	**0.97**	1.00						
Cu	-0.01	**-0.70**	0.16	**0.55**	n.v.	**-0.61**	0.15	-0.24	-0.17	**0.80**	-0.15	**0.55**	**0.68**	**0.89**	0.42	**0.94**	**0.92**	1.00					
Zn	0.20	**-0.62**	-0.07	**0.74**	n.v.	**-0.69**	0.21	**-0.55**	-0.35	**0.77**	-0.27	0.36	**0.71**	**0.93**	**0.51**	**0.94**	**0.94**	**0.84**	1.00				
As	0.02	-0.27	-0.21	0.32	n.v.	0.08	0.14	**-0.56**	-0.47	0.13	-0.49	-0.05	0.15	0.41	**0.76**	0.44	0.43	0.29	0.36	1.00			
Cd	0.29	**-0.74**	0.02	**0.67**	n.v.	-0.49	0.27	**-0.55**	-0.33	**0.60**	-0.44	0.36	**0.66**	**0.62**	0.26	**0.69**	**0.75**	**0.64**	**0.72**	0.28	1.00		
Pb	0.47	-0.21	-0.07	**0.73**	n.v.	**-0.61**	-0.02	-0.42	-0.08	0.49	0.07	0.20	**0.61**	**0.69**	0.10	**0.59**	**0.59**	0.43	**0.68**	-0.04	0.31	1.00	
MPI_8	0.18	**-0.71**	-0.06	**0.74**	n.v.	**-0.58**	0.31	**-0.63**	-0.45	**0.70**	-0.43	0.33	**0.69**	**0.93**	**0.66**	**0.94**	**0.96**	**0.82**	**0.93**	**0.56**	**0.74**	**0.61**	1.00

Appendix 4.4. The correlation between the *C. gigas* density, size, abiotic variables, landscape development, and tissue trace metal concentration with significant values in bold.

Abbreviations are: Tissue dry weight (tissue wgt), temperature (temp), salinity (sal), dissolved oxygen (DO), landscape development intensity (LDI), and impervious surface area (Imp. Surf. %), and the Metal Pollution Index (MPI8).

	Imp. Surf.	LDI	Tissue wgt	CI	Length	Density	Temp (°C)	Sal (ppt)	DO (mg/L)	pH	Cr	Mn	Co	Ni	Cu	Zn	As	Cd	Pb	MPI_8
Imp. Surf.	1.00																			
LDI	**1.00**	1.00																		
Tissue wgt	-0.11	-0.11	1.00																	
CI	0.19	0.19	0.07	1.00																
Length	-0.09	-0.09	**0.89**	-0.12	1.00															
Density	**0.81**	**0.80**	0.02	**0.23**	0.01	1.00														
Temp (°C)	**-0.43**	**-0.42**	0.04	-0.20	0.05	**-0.78**	1.00													
Sal (ppt)	0.10	0.10	**-0.24**	**0.29**	-0.19	0.02	0.19	1.00												
DO (mg/L)	-0.15	-0.15	**0.37**	-0.16	**0.30**	0.12	0.09	0.00	1.00											
pH	-0.10	-0.10	**0.34**	-0.18	**0.27**	0.18	0.00	-0.09	**0.97**	1.00										
Cr	0.23	0.23	-0.15	0.12	0.01	0.27	-0.27	0.29	0.15	0.12	1.00									
Mn	0.06	0.06	-0.17	-0.17	0.10	0.12	-0.12	0.10	0.13	0.10	**0.87**	1.00								
Co	0.16	0.16	-0.14	-0.01	0.06	0.17	-0.17	0.24	0.06	0.01	**0.87**	**0.91**	1.00							
Ni	0.23	0.23	-0.26	0.25	-0.09	0.11	-0.11	**0.48**	-0.04	-0.10	**0.90**	**0.82**	**0.91**	1.00						
Cu	0.23	0.23	0.05	-0.44	0.34	0.17	-0.17	-0.26	**-0.42**	**-0.42**	0.23	0.31	0.36	0.22	1.00					
Zn	0.21	0.21	0.19	-0.37	**0.52**	0.30	-0.30	**-0.45**	-0.29	-0.31	0.08	0.19	0.25	0.06	**0.90**	1.00				
As	0.14	0.14	-0.12	**-0.64**	0.33	0.12	-0.12	**-0.51**	**-0.44**	-0.40	0.10	0.27	0.29	0.09	**0.85**	**0.83**	1.00			
Cd	**0.42**	**0.42**	-0.29	-0.27	0.08	0.27	-0.27	0.07	**-0.43**	**-0.44**	**0.49**	**0.54**	**0.65**	**0.58**	**0.78**	**0.67**	**0.70**	1.00		
Pb	**0.61**	**0.61**	-0.37	0.21	-0.13	**0.46**	**-0.46**	**0.41**	-0.28	-0.32	**0.77**	**0.65**	**0.75**	**0.79**	**0.41**	0.29	0.23	**0.75**	1.00	
MPI_8	0.27	0.27	-0.27	-0.13	0.11	0.21	-0.21	0.17	-0.12	-0.13	**0.76**	**0.78**	**0.85**	**0.78**	**0.65**	**0.53**	**0.56**	**0.87**	**0.80**	1.00

Chapter 5 Appendices

Appendix 5.1. The correlation between perceived fishery abundance, condition and environmental indices scores, and the main change score. Significant results are bold.

	Partipant experience	Clams and cockles	Saltwater clams	Saltwater mussels	Galaxiids	Flounder	Site score	Catchment score	Enviro. index	Main changes score
Partipant experience	1.00									
Clams and cockles	-0.34	1.00								
Saltwater clams	0.02	0.42	1.00							
Saltwater mussels	-0.45			1.00						
Galaxiids	-0.51	0.00	-0.30		1.00					
Flounder	0.05	**0.77**	0.38	1.00	1.00	1.00				
Site score	**-0.39**	0.17	-0.35	0.53	-0.14	-0.21	1.00			
Catchment score	**-0.39**	0.40	-0.31	0.17	-0.12	-0.20	**0.51**	1.00		
Enviro. index	**-0.26**	-0.01	0.01	0.33	0.06	-0.45	0.06	0.02	1.00	
Main changes score	**0.61**	-0.39	0.50	-0.49	-0.64	-0.25	**-0.44**	**-0.46**	**-0.26**	1.00

Appendix 6.1. Global Position System (GPS) for the shellfish study sites in Waitaha, Canterbury.

Area	Site	GPS Co-ordinates **S**	**E**
Saltwater Creek	SCR	43°16.039'	172°43.011'
	SCM	43°16.116'	172°43.302'
Avon-Heathcote	PJ	43°33.231'	172°44.794'
Estuary	Tern	43°33.216'	172°44.587'
	Heathcote	43°33.381'	172°42.573'
	Beachville	43°33.356'	172°43.895'
Rāpaki	Beach	43°36.482'	172°41.070'
	Rocky	43°36.469'	172°41.061'
Koukourārata	Pā	43°39.190'	172°49.909'
	Rocky	43°38.679'	172°50.257'

Appendix 6.2. Comparison of abiotic readings using ANOVA: (1) sediment grain size composition and (2) water quality metrics and of: catchments influenced by (A) low salinity and high salinity input, (B) combined high salinity input, and (C) rocky sites. The interaction findings (e.g. site x season) are not provided in the tables.

(1) Sediment grain size composition

		>2mm			>1mm			>500µm			>250µm			>125µm			>63µm			<63µm		
Effect	DF	MS	F	p	MS	F	p	MS	F	p	MS	F	p	MS	F	p	MS	F	p	MS	F	p
(A) Clam beds: paired influenced by low salinity and high salinity input																						
Site	5	1.47	2.36	0.05	3.51	7.96	**<0.0001**	5.22	15.74	**<0.0001**	5.36	9.41	**<0.0001**	211.78	27.83	**<0.0001**	20.12	4.88	**<0.01**	61.50	48.52	**<0.0001**
Season	1	0.15	0.25	0.62	0.16	0.36	0.55	1.13	3.41	0.07	0.49	0.87	0.36	38.50	5.06	**<0.05**	7.16	1.74	0.19	0.86	0.67	0.42
Year	1	0.69	1.11	0.30	0.15	0.35	0.56	0.23	0.70	0.41	0.03	0.05	0.82	6.97	0.92	0.34	1.94	0.47	0.50	1.49	1.18	0.28
(B) Clam beds: influenced by high salinity input																						
Site	4	0.9	0.8	0.5	1.2	2.4	0.1	2.7	4.9	**<0.01**	52.0	64.4	**<0.0001**	198.3	29.9	**<0.0001**	96.5	16.9	**<0.0001**	49.6	17.1	**<0.0001**
Season	1	1.2	1.1	0.3	2.4	4.8	**<0.05**	2.2	3.9	0.1	0.1	0.1	0.8	111.6	16.8	**<0.001**	149.7	26.2	**<0.0001**	15.4	5.3	**<0.05**
Year	1	2.2	2.0	0.2	0.6	1.1	0.3	2.3	4.0	0.1	27.5	34.1	**<0.0001**	6.4	1.0	0.3	65.1	11.4	**<0.01**	10.2	3.5	**0.1**
(C) Oyster sites (rocky)																						
Site	1	<0.01	<0.01	0.99	0.53	0.14	0.71	3.55	1.00	0.33	28.00	7.84	**<0.05**	14.08	1.22	0.28	115.41	5.65	**<0.05**	3.27	3.69	0.07
Season	1	1.87	0.16	0.69	2.08	0.55	0.47	7.01	1.97	0.18	41.07	11.50	**<0.01**	41.97	3.65	0.07	4.63	0.23	0.64	0.02	0.03	0.87
Year	1	0.20	0.02	0.90	4.95	1.32	0.27	5.29	1.49	0.24	0.37	0.10	0.75	3.36	0.29	0.60	226.40	11.09	**<0.01**	3.71	4.18	0.05

(2) Water readings

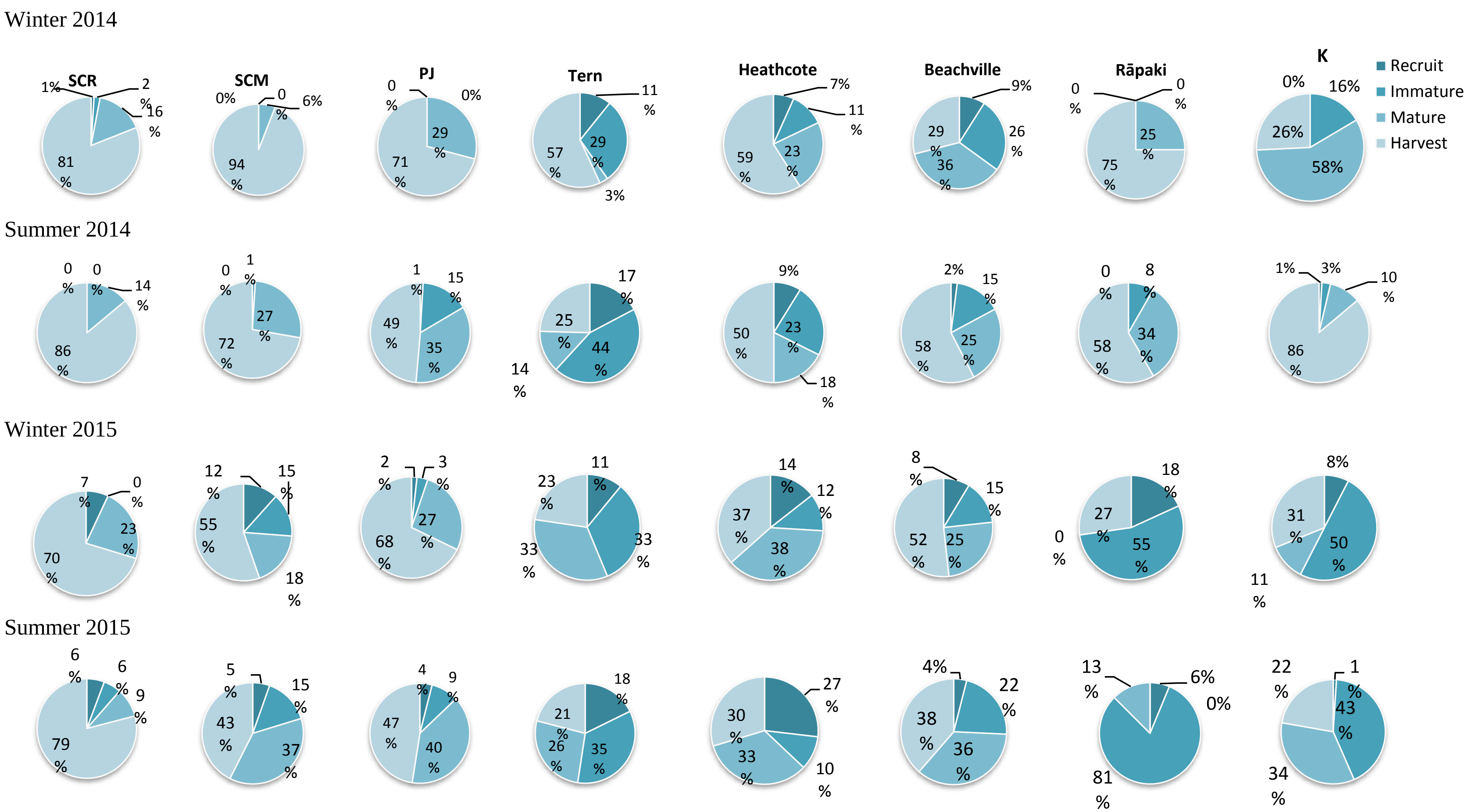
		Salinity (ppt)			Temperature (˚C)			pH			DO (mg/L)		
Effect	DF	MS	F	p-value	MS	F	p-value	MS	F	p-value	MS	F	p-value
(A) Clam beds: paired influenced by low salinity and high salinity input													
Site	5	787.79	540.46	**<0.0001**	9.61	86.33	**<0.0001**	4.94	126.33	**<0.0001**	4.75	34.87	**<0.0001**
Season	1	2.07	1.42	0.24	641.72	5762.83	**<0.0001**	5.21	133.23	**<0.0001**	49.55	363.73	**<0.0001**
Year	1	401.39	275.37	**<0.0001**	115.65	1038.55	**<0.0001**	0.20	5.05	**<0.05**	3.77	27.66	**<0.0001**
(B) Clam beds: influenced by high salinity input													
Site	4	786.79	800.72	**<0.0001**	12.01	182.47	**<0.0001**	6.47	298.52	**<0.0001**	3.65	26.93	**<0.0001**
Season	1	15.60	15.87	**<0.001**	462.81	7033.51	**<0.0001**	9.33	430.06	**<0.0001**	14.72	108.59	**<0.0001**
Year	1	637.91	649.21	**<0.0001**	52.11	791.91	**<0.0001**	2.31	106.71	**<0.0001**	1.28	9.41	**<0.01**
(C) Oyster sites (rocky)													
Site	1	1.45	0.49	0.50	9.88	83.73	**<0.0001**	1.09	9.73	**<0.01**	29.11	129.38	**<0.0001**
Season	1	39.78	13.33	**<0.01**	429.26	3637.16	**<0.0001**	3.85	34.42	**<0.0001**	0.09	0.38	0.55
Year	1	41.34	13.85	**<0.01**	4.08	34.60	**<0.0001**	2.48	22.16	**<0.001**	0.62	2.75	0.12

Appendix 6.3. The *A. stutchburyi*: (1) population distribution, (2) size class composition, and the analysis of (3) density and length, with significant values in bold.

(1) The population distribution measurements for each sampling season, with: highly skewed (HS), moderately skewed (MS), and symmetrical (S) distributions.

Period	Site	Mean ±S.E.	Mode	G_1	Pattern		Site	Mean ±S.E.	Mode	G_1	Pattern	
W2014		35.8±2.3	38	-1.38	HS			36.4±1.4	37	-0.47	S	Unimodal
S2014	Saltwater Creek River	36.5±2.1	41	-0.6	MS	Unimodal	Saltwater Creek High salinity	33.1±1.7	39	-0.65	MS	
W2015		31.2±2.0	30	-1.53	HS			27.4±4.9	37	-0.65		
S2015		33.7±2.8	40	-1.38				26.3±2.9	27	-0.76		
W2014		31.2±0.8	31	1.76	HS			27.3±5.5	10, 35	-0.29	S	Bimodal
S2014	Pleasant Pt. Jetty	26.9±2.0	33	-0.67	MS	Unimodal	Tern	19.3±4.4	12	0.69	MS	
W2015		30.5±1.1	32	-1.91	HS			22.0±4.7	21	0.67		Unimodal
S2015		26.6±3.2	30	-1.29				20.6±4.1	8, 12, 24	0.54		Multimodal
W2014		27.0±2.2	30	-1.55	HS		Beachville	24.9±4.7	11, 27, 30,	1.11	HS	Multimodal
S2014		24.4±2.6	30	-0.72	MS	Unimodal		31.9±3.7	22, 25, 41	-0.2	S	
W2015	Heathcote	23.5±3.2	30	-0.84				28.6±4.3	10, 40, 45	-0.29		
S2015		21.1±4.3	7, 29, 31	-0.39	S	Multimodal		27.2±3.2	23, 27, 33	0.19		
W2014		38.0±3.6	No value	-1.33	n/a	n/a		26.4±4.1	27	3.74	HS	Unimodal
S2014		35.6±4.6	26, 47	-0.36	S	Bi-modal		40.8±3.8	32, 48	-0.14	S	Bi-modal
W2015	Rāpaki	16.5±5.2	11, 30	1.25	HS		Koukourārata	23.0±4.9	12	0.94	MS	Unimodal
S2015		15.4±2.5	15	1.13		Unimodal		24.3±5.4	20	1.22	HS	

(2) The size class composition (%) of recruit (≥2.5 to <10mm), immature (>10 to <20mm), medium/mature (≥20 to <30mm), and recreational clams (≥30mm).



(3) The effect of site, season, and year on *A. stutchburyi* density (individual per m²) and shell length (mm) and the significant values are in bold.

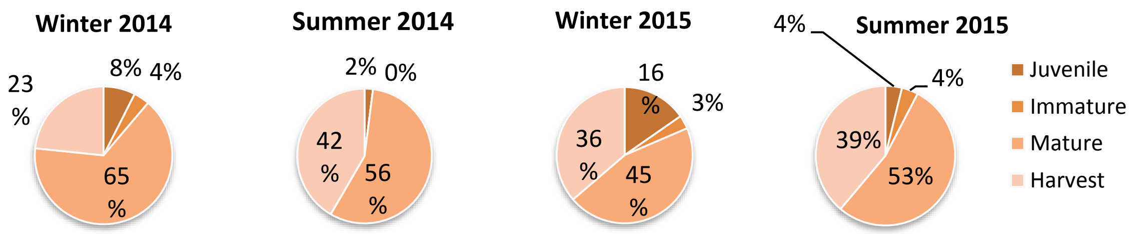
Cockles		Density			Length		
Effect	DF	MS	F	p-value	MS	F	p-value
Site	7	171.47	9.69	**<0.0001**	706.03	11.09	**<0.0001**
Season	1	14.08	0.80	0.37	120.73	1.90	0.17
Year	1	76.62	4.33	**<0.05**	2886.98	45.34	**<0.0001**
Site*Season	7	26.11	1.47	0.18	140.97	2.21	**<0.05**
Site*Year	7	69.86	3.95	**<0.001**	210.48	3.31	**<0.01**
Season*Year	1	0.02	0.00	0.97	103.81	1.63	0.20
Site*Season*Year	7	24.58	1.39	0.21	105.95	1.66	0.12

Appendix 6.4. The *P. australis* (1) population distribution, (2) size class composition, and the analysis of (3) density and length, and (3) condition index. Significant values are provided in bold.

(1) The population distribution measurements for each season.

Period	Length (mm)		Distribution		
	Mean ±S.E.	Mode	G_1	Kurtosis	Pattern
Winter 2014	45.0±3.9	47	-1.8	4.0	Highly Skewed Unimodal
Summer 2014	48.9±2.9	49	-1.8	9.2	
Winter 2015	43.0±6.8	50	-1.7	1.6	
Summer 2015	47.2±4.0	48	-2.8	9.3	

(2) The *P. australis* size class (%): of juvenile (<25mm), mature (≥40 mm), and harvest sized clams (≥50 mm) for each season.



(3) The effect of season and year on *P. australis* density (individuals per m²) and length (mm) using ANOVA.

		Density			Length		
Effect	DF	MS	F	p-value	MS	F	p-value
Season	1	22364.59	0.27	0.61	242.48	8.95	**<0.01**
Year	1	63428.59	0.77	0.39	20.36	0.75	0.40
Season*Year	1	2840.14	0.03	0.86	113.50	4.19	0.06

(4) Comparison of *P. australis* condition index across year and season using separate slopes analysis.

Effect	DF	MS	F	p-value
Year	1	1878.64	3.92	0.05
Season	1	2795.65	5.83	**<0.05**
Year*Season*Length	4	7678.17	16.02	**<0.0001**
Year*Season*Soft tissue weight (g)	4	18774.13	39.18	**<0.0001**

Appendix 6.5. The *T. chilensis* population (1) density and length, (2) population distribution measurements, and (3) size class measurements. Significant values are provided in bold.

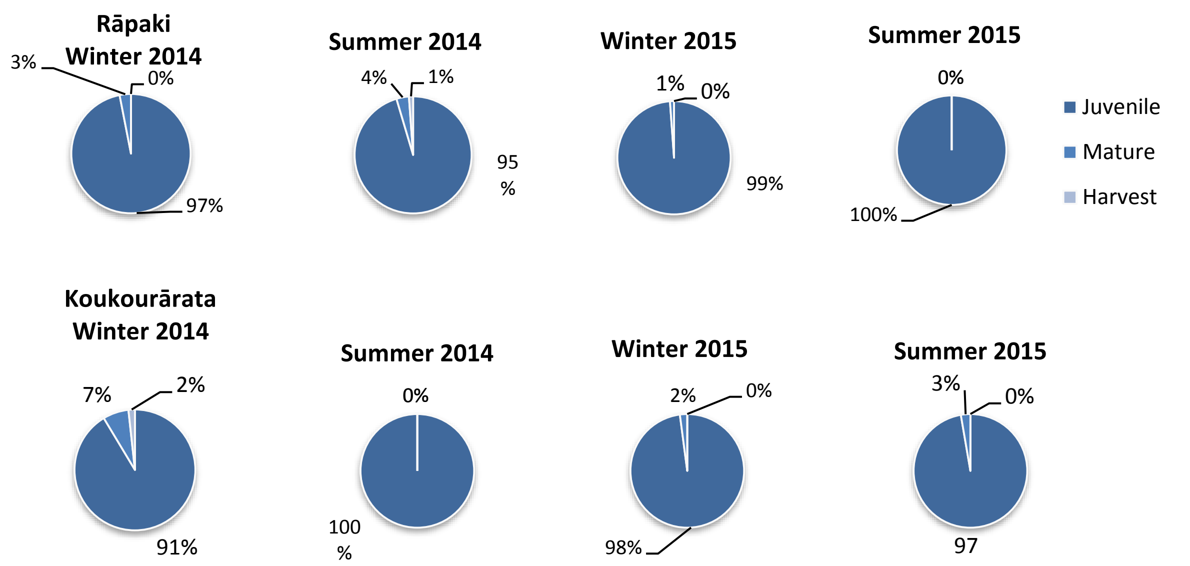
(1) Comparison of *T. chilensis* density (individuals per m²) and length (mm) across site, season, year, and sampling period (e.g. winter 2014, winter 2015) using Kruskal-Wallis analysis.

		Density		Length	
Effect	DF	H	p-value	H	p-value
Site	1	1.44	0.23	2.53	0.11
Year	1	0.44	0.51	0.02	0.90
Season	1	0.86	0.35	1.38	0.24
Sampling period	3	7.46	0.06	1.66	0.65

(2) Population distribution of *Tiostrea chilensis*

Period	Site	Length (mm)		Distribution			
		Mean ±S.E	Mode	G_1	Kurtosis	Pattern	
Winter 2014	Rāpaki	27.2±1.5	20	0.4	<0.01	Symmetrical	Unimodal
	Koukourārata	34.8±1.4	35	0.3	-0.6		
Summer 2014	Rāpaki	31.9±2.2	30	0.9	13.1	Moderately Skewed	
	Koukourārata	29.3±1.8	20	0.4	-0.4	Symmetrical	
Winter 2015	Rāpaki	31.6±2.3	30	-0.1	-0.8		
	Koukourārata	35.8±11.6	25	-0.03	41.5		
Summer 2015	Rāpaki	28.6±1.9	33	-0.03	-0.7		
	Koukourārata	29.8±2.8	38	-0.1	-0.6		

(3) *T. chilensis* size class (%) of juvenile (<50mm), mature (≥50mm), and harvest size oysters (≥58mm) for each season.



Appendix 6.6. Contaminant data over time for sediment, and the tissue samples of *A. stutchburyi*, *P. australis*, and *T. chilensis*.

Comparison of log-transformed sediment trace metal concentrations (ppm dry weight) using ANOVA and significant values are in bold.

		As			Cd			Co			Cr			Cu		
Effect	DF	MS	F	p-value	MS	F	p-value	MS	F	p-value	MS	F	p-value	MS	F	p-value
Site	9	0.11	16.17	**<0.0001**	0.01	4.63	**<0.001**	0.12	18.16	**<0.0001**	0.16	29.22	**<0.0001**	0.11	10.90	**<0.0001**
Season	1	0.04	5.15	**<0.05**	0.01	2.99	0.09	0.00	0.65	0.42	0.01	2.21	0.14	0.00	0.21	0.65
Year	1	0.04	6.25	**<0.05**	0.01	4.79	**<0.05**	0.06	8.44	**<0.01**	0.10	18.73	**<0.0001**	0.22	22.73	**<0.0001**
Site*Season	9	0.01	0.85	0.57	0.01	2.77	**<0.05**	0.01	1.24	0.28	0.01	1.41	0.20	0.02	1.67	0.11
Site*Year	9	0.02	3.48	**<0.05**	0.01	2.79	**<0.05**	0.01	1.34	0.23	0.02	4.41	**<0.0001**	0.02	1.98	0.05
Season*Year	1	0.10	14.46	**<0.001**	0.01	2.72	0.10	0.07	10.38	**<0.05**	0.22	40.97	**<0.0001**	0.02	1.57	0.21
Site*Season*Year	9	0.01	1.17	0.32	0.01	2.84	**<0.05**	0.02	2.35	**<0.05**	0.01	1.83	0.07	0.03	2.99	**<0.01**
		Mn			Ni			Pb			Zn			MPI_8		
Effect	DF	MS	F	p-value	MS	F	p-value	MS	F	p-value	MS	F	p-value	MS	F	p-value
Site	9	0.07	10.25	**<0.0001**	0.11	25.85	**<0.0001**	0.12	15.75	**<0.0001**	0.17	10.89	**<0.0001**	0.06	12.36	**<0.0001**
Season	1	<0.0001	0.01	0.93	0.01	1.68	0.20	0.08	10.56	**<0.01**	0.00	0.24	0.62	0.01	2.51	0.12
Year	1	0.11	16.53	**<0.001**	0.04	9.77	**<0.05**	0.05	7.13	**<0.05**	0.16	10.36	**<0.01**	0.11	20.53	**<0.0001**
Site*Season	9	0.01	1.79	0.08	0.00	1.14	0.35	0.01	0.88	0.55	0.01	0.78	0.64	0.01	1.44	0.19
Site*Year	9	0.01	1.69	0.10	0.01	2.26	**<0.05**	0.02	2.10	**<0.05**	0.05	3.39	**<0.01**	0.01	1.67	0.11
Season*Year	1	0.21	30.93	**<0.0001**	0.06	14.15	**<0.001**	0.15	18.94	**<0.0001**	0.04	2.53	0.12	0.04	6.83	**<0.05**
Site*Season*Year	9	0.03	3.77	**<0.001**	0.01	2.99	**<0.01**	0.01	1.17	0.33	0.02	1.14	0.34	0.01	2.59	**<0.05**

Comparison of trace metal concentrations (ppm dry weight) of *A. stutchburyi* tissue from Rāpaki beach using separate slopes. Significant values are in bold.

		As			Cd			Co			Cr			Cu		
Effect	DF	MS	F	p-value	MS	F	p-value	MS	F	p-value	MS	F	p-value	MS	F	p-value
Site	7	0.06	2.47	**<0.05**	0.00	3.05	**<0.05**	0.02	3.05	**<0.05**	0.03	2.27	**<0.05**	0.02	1.93	0.07
Season	1	0.10	3.76	0.06	0.00	1.83	0.18	0.01	2.56	0.11	0.08	6.04	**<0.05**	0.03	2.44	0.12
Year	1	0.08	2.92	0.09	0.00	2.14	0.15	0.01	1.78	0.19	0.00	0.18	0.67	0.07	6.48	**<0.05**
Site*Season*Year*Length	32	0.05	1.97	**<0.05**	0.00	1.75	**<0.05**	0.01	1.88	**<0.05**	0.02	1.30	0.16	0.02	1.82	**<0.05**
Site*Season*Year*Soft tissue weight	32	0.06	2.16	**<0.01**	0.00	2.01	**<0.01**	0.01	2.17	**<0.01**	0.02	1.62	**<0.05**	0.02	2.14	**<0.01**
		Mn			Ni			Pb			Zn			MPI_8		
Effect	DF	MS	F	p-value	MS	F	p-value	MS	F	p-value	MS	F	p-value	MS	F	p-value
Site	7	0.06	2.12	**<0.05**	0.04	2.44	**<0.05**	0.03	5.11	**<0.001**	0.02	1.13	0.35	0.03	2.95	**<0.05**
Season	1	0.05	1.57	0.21	0.03	2.27	0.14	0.01	1.32	0.25	0.01	0.45	0.50	0.04	4.09	**<0.05**
Year	1	0.03	0.93	0.34	0.02	1.68	0.20	0.00	0.21	0.65	0.05	2.57	0.11	0.02	2.16	0.14
Site*Season*Year*Length	32	0.03	0.97	0.53	0.02	1.55	0.05	0.01	2.03	**<0.01**	0.02	1.09	0.36	0.01	1.52	0.06
Site*Season*Year*Soft tissue weight	32	0.03	1.10	0.35	0.03	1.86	**<0.05**	0.01	1.38	0.12	0.03	1.71	**<0.05**	0.02	1.78	**<0.05**

Comparison of trace metal concentrations (ppm dry weight) of *P. australis* tissue from Rāpaki beach using separate slopes. Significant values are in bold.

		As			Cd			Co			Cr			Cu		
Effect	DF	MS	F	p-value	MS	F	p-value	MS	F	p-value	MS	F	p-value	MS	F	p-value
Season	4	0.18	0.02	0.89	0.01	3.42	0.09	0.04	0.23	0.64	0.12	0.72	0.41	7.61	4.17	0.06
Year	4	10.00	1.09	0.32	0.00	1.12	0.31	0.03	0.19	0.67	0.08	0.46	0.51	0.11	0.06	0.81
Season*Year*Length	1	8.31	0.91	0.49	0.01	3.57	**<0.05**	0.12	0.75	0.58	0.30	1.74	0.21	8.63	4.73	**<0.05**
Season*Year*Soft tissue weight	1	11.81	1.29	0.33	0.01	4.95	**<0.05**	0.18	1.07	0.41	0.30	1.76	0.20	9.16	5.02	**<0.05**
		Log-Mn			Ni			Pb			Zn			MPI_8		
Effect	DF	MS	F	p-value	MS	F	p-value	MS	F	p-value	MS	F	p-value	MS	F	p-value
Season	4	0.01	0.10	0.76	0.07	0.60	0.45	2.14	3.16	0.10	268.21	2.19	0.16	1.21	0.92	0.36
Year	4	0.02	0.13	0.72	0.09	0.83	0.38	0.01	0.02	0.88	73.59	0.60	0.45	0.04	0.03	0.86
Season*Year*Length	1	0.01	0.11	0.98	0.19	1.72	0.21	0.78	1.16	0.38	403.28	3.30	**<0.05**	1.22	0.92	0.48
Season*Year*Soft tissue weight	1	0.02	0.20	0.93	0.19	1.67	0.22	0.68	1.00	0.45	431.14	3.53	**<0.05**	1.65	1.25	0.34

Comparison of trace metal concentrations (ppm dry weight) of *T. chilensis* tissue using Mann-Whitney U. Significant values are in bold.

	Site		Season		Year	
Element	U	p-value	U	p-value	U	p-value
As	274	0.99	252	0.62	181	**<0.05**
Cd	91	**<0.0001**	179	**<0.05**	232	0.35
Co	252	0.63	121	**<0.01**	225	0.28
Cr	262	0.79	94	**<0.001**	145	**<0.05**
Cu	21	**<0.0001**	270	0.91	270	0.91
Mn	207	0.15	175	**<0.05**	237	0.41
Ni	243	0.50	63	**<0.0001**	250	0.59
Pb	241	0.48	202	0.12	257	0.69
Zn	77	**<0.0001**	257	0.69	184	0.05
MPI_8	270	0.92	94	**<0.001**	149	**<0.05**

Appendix 6.7. Correlation analysis

1) Correlation results between the *A. stutchburyi* biological indices with land-condition, abiotic variables, and both sediment and tissue contaminant concentrations, with significant values in bold.

	Recruit Density		Mean density (Ave. Density)		Max shell length (Max SL)		Mean shell length (Ave.SL)		Condition Index (CI)	
Variables	R	p-value	R	p-value	R	p-value	R	p-value	R	p-value
Landscape condition and abiotic:										
Impervious surface	0.34	**<0.01**	0.07	0.49	-0.09	0.36	-0.40	**<0.0001**	-0.24	**<0.05**
LDI	0.40	**<0.001**	0.19	0.06	-0.18	0.07	-0.22	*0.03*	-0.28	**<0.01**
Salinity	0.08	0.45	0.21	*0.04*	0.18	0.08	-0.18	0.08	0.42	**<0.0001**
Temperature	0.42	**<0.0001**	0.19	0.07	-0.07	0.47	-0.50	**<0.0001**	0.50	**<0.0001**
pH	0.36	**<0.001**	0.04	0.68	0.21	*0.04*	-0.32	**<0.01**	0.25	**<0.05**
Dissolved Oxygen	0.23	**<0.05**	0.01	0.89	0.05	0.63	-0.28	**<0.01**	-0.05	0.60
<63 µm	-0.23	**<0.05**	0.03	0.80	0.36	**<0.001**	-0.02	0.82	-0.17	0.10
>63 µm	-0.17	0.10	0.21	*0.04*	0.24	*0.02*	0.07	0.52	0.12	0.25
>125 µm	0.27	**<0.01**	-0.11	0.30	-0.19	0.06	0.08	0.41	-0.27	**<0.01**
>250 µm	-0.22	*0.03*	-0.46	**<0.0001**	0.00	0.97	-0.42	**<0.0001**	-0.24	**<0.05**
>500	-0.28	**<0.01**	-0.21	*0.04*	0.23	*0.03*	-0.34	**<0.001**	0.09	0.36
>1mm	-0.18	0.07	0.00	0.97	0.27	**<0.01**	-0.16	0.12	0.12	0.26
>2mm	0.02	0.85	0.07	0.51	-0.01	0.91	-0.03	0.75	0.26	**<0.01**
Total volatile solids	0.11	0.28	0.09	0.38	0.05	0.61	-0.02	0.87	-0.36	**<0.001**
Pore water	0.19	0.06	0.22	*0.03*	0.11	0.29	-0.19	0.06	0.30	**<0.01**
Sediment:										
As	-0.62	**<0.0001**	-0.43	**<0.0001**	-0.05	0.65	0.17	0.10	-0.19	0.07
Cd	-0.18	0.07	-0.05	0.64	-0.18	0.08	0.11	0.29	-0.53	**<0.0001**
Co	-0.31	**<0.01**	0.11	0.29	0.35	**<0.001**	0.21	*0.04*	0.07	0.48
Cr	-0.45	**<0.0001**	-0.07	0.49	0.16	0.12	0.37	**<0.001**	-0.25	**<0.05**
Cu	-0.47	**<0.0001**	-0.32	**<0.05**	-0.23	*0.03*	0.37	**<0.001**	-0.45	**<0.0001**
Mn	-0.38	**<0.0001**	-0.07	0.50	0.26	**<0.001**	0.28	**<0.01**	-0.12	0.24
Ni	-0.29	**<0.01**	0.04	0.73	0.14	0.17	0.39	**<0.0001**	-0.12	0.23
Pb	-0.48	**<0.0001**	-0.49	**<0.0001**	-0.31	**<0.001**	0.14	0.17	-0.58	**<0.0001**
Zn	-0.16	0.13	-0.09	0.40	-0.15	0.14	0.10	0.35	-0.47	**<0.0001**
MPI_8	0.11	0.31	0.11	0.31	-0.06	0.54	-0.26	**<0.05**	-0.24	**<0.05**
Tissue:										
As	-0.06	0.53	-0.31	**<0.01**	0.11	0.30	-0.31	**<0.01**	-0.57	**<0.0001**
Cd	0.03	0.78	-0.09	0.40	0.07	0.52	0.09	0.41	0.19	0.06
Co	-0.19	0.06	-0.43	**<0.0001**	0.08	0.42	-0.40	**<0.0001**	-0.34	**<0.001**
Cr	-0.28	**<0.01**	-0.42	**<0.0001**	0.12	0.25	-0.44	**<0.0001**	-0.67	**<0.0001**
Cu	-0.13	0.21	-0.13	0.21	0.14	0.18	-0.26	**<0.05**	-0.18	0.08
Mn	-0.52	**<0.0001**	-0.06	0.55	0.10	0.31	-0.41	**<0.0001**	-0.22	**<0.05**
Ni	-0.20	0.06	-0.41	**<0.0001**	0.18	0.08	-0.49	**<0.0001**	-0.42	**<0.0001**
Pb	-0.20	*0.05*	-0.40	**<0.001**	-0.14	0.19	-0.37	**<0.001**	-0.70	**<0.0001**
Zn	-0.06	0.59	-0.09	0.36	0.05	0.64	-0.09	0.37	-0.41	**<0.0001**
MPI_8	-0.26	**<0.01**	-0.45	**<0.0001**	0.06	0.56	-0.39	**<0.0001**	-0.47	**<0.0001**
E. coli	0.13	0.22	0.05	0.64	0.14	0.17	0.13	0.20	-0.31	**<0.01**

2) Correlation results of the water metrics and landscape condition with tissue and sediment conditions. Significant values corrected by Benjamini-Hochberg procedure are in bold.

	LDI		Impervious surface		pH		Salinity		DO		Temperature	
Variables	R	p-value	R	p-value	R	p-value	R	p-value	R	p-value	R	p-value
Sediment:												
As	-0.65	**<0.0001**	-0.34	**<0.001**	-0.23	**<0.05**	-0.08	0.46	-0.11	0.28	-0.15	0.15
Cd	0.47	**<0.0001**	0.39	**<0.0001**	-0.25	**<0.05**	-0.36	**<0.001**	-0.28	**<0.01**	-0.36	**<0.001**
Co	-0.36	**<0.001**	-0.32	**<0.01**	-0.37	**<0.0001**	-0.08	0.41	-0.31	**<0.01**	-0.20	0.05
Cr	0.05	0.66	-0.03	0.75	-0.37	**<0.001**	-0.37	**<0.001**	-0.36	**<0.001**	-0.42	**<0.0001**
Cu	0.05	0.66	-0.13	0.20	-0.58	**<0.0001**	-0.49	**<0.0001**	-0.21	*0.04*	-0.53	**<0.0001**
Mn	-0.08	0.43	-0.05	0.64	-0.23	**<0.05**	-0.20	0.05	-0.33	**<0.01**	-0.33	**<0.01**
Ni	0.06	0.57	-0.22	*0.03*	-0.47	**<0.0001**	-0.41	**<0.0001**	-0.23	**<0.05**	-0.46	**<0.0001**
Pb	-0.20	*0.05*	-0.01	0.93	-0.13	0.22	-0.17	0.09	0.18	0.08	-0.42	**<0.0001**
Zn	0.28	**<0.01**	0.25	**<0.05**	-0.34	**<0.001**	-0.41	**<0.0001**	-0.25	**<0.05**	-0.30	**<0.01**
MPI$_8$	0.02	0.83	0.11	0.30	-0.18	0.07	-0.27	**<0.01**	0.31	**<0.01**	-0.03	0.77
Tissue:												
As	0.41	**<0.0001**	0.30	**<0.01**	0.02	0.82	-0.44	**<0.0001**	0.07	0.51	**-0.46**	**<0.0001**
Cd	0.05	0.62	-0.33	**<0.01**	-0.20	*0.05*	0.04	0.69	-0.04	0.73	-0.09	0.41
Co	-0.14	0.16	-0.21	*0.04*	-0.07	0.48	-0.21	*0.04*	0.12	0.25	*-0.22*	*0.03*
Cr	0.21	*0.04*	0.21	*0.04*	-0.03	0.78	-0.13	0.22	-0.15	0.15	**-0.45**	**<0.0001**
Cu	0.33	**<0.001**	0.15	0.14	-0.04	0.68	-0.35	**<0.001**	-0.13	0.20	**-0.37**	**<0.001**
Mn	-0.53	**<0.0001**	-0.19	0.07	0.03	0.75	0.09	0.41	-0.03	0.75	-0.05	0.64
Ni	0.01	0.95	0.00	0.98	-0.16	0.13	-0.36	**<0.001**	-0.04	0.73	-0.19	0.06
Pb	0.20	0.06	0.37	**<0.001**	0.08	0.46	-0.13	0.21	0.02	0.88	**-0.29**	**<0.01**
Zn	0.36	**<0.001**	0.19	0.06	-0.12	0.26	-0.59	**<0.0001**	-0.10	0.32	**-0.46**	**<0.0001**
MPI$_8$	0.08	0.45	-0.02	0.84	-0.23	*0.03*	-0.19	0.06	-0.12	0.26	**-0.35**	**<0.01**
E. coli	0.19	0.06	-0.05	0.66	-0.14	0.19	-0.49	**<0.0001**	0.25	*0.02*	**-0.49**	**<0.0001**

Appendix 7.1. Potential anthropogenic sources of trace elements in the environment

Element	Potential anthropogenic sources
As	Wood preserver, pesticides (including sheep dips, cotton plants), herbicides, fertilisers. Waste fluid from geothermal power generation or from tanning (e.g. leather or wool) also contains arsenic. See CCA.
“CCA”	Copper chromated arsenic (CCA) is used to make “pressure-treated” timber.
Cd	Non-ferrous metal production, batteries, pigments, metal coatings, plastics, phosphate fertiliser.
	Lubricating oils, diesel oils, tyres, phosphate fertilisers, sewage sludge, insecticides, electroplating, pigments, batteries, coal and oil combustion, non-ferrous metal production, refuse incineration, iron and steel manufacturing
Cr	Released from manufacture, use, and disposal of chromium-based products. Plating. See CCA.
Cu	Mining activities (e.g. coal), concrete and asphalt, wire, plumbing pipes, and sheet material (risk due to corrosion or runoff). Copper compounds are also used in agriculture (treat mildew, water treatment), wood preservatives (See CCA), leather, and fabrics.
Hg	Methyl mercury is used to produce chlorine gas, caustic soda, thermometers, dental fillings, and batteries. Metallic mercury is used in antiseptic creams and other creams/ointments. Inorganic Hg enters the air from mining ore deposits, burning coal and waste, and manufacturing plants.
Mn	Manganese occurs in aerosol input (manufacturing), irrigation waters (fertiliser), steel production, and additive to gasoline.
Ni	Alloys (combined with Fe, Cu, Cr, Zn) for coins, jewellery, valves, and heat exchangers. Stainless steel, plating, colour ceramics, batteries, catalysts substances, phosphate fertiliser.
Pb	(Formerly) leaded gasoline, artificial turf, toys, water, lead fumes (metal processing), lead-based paints, phosphate fertiliser.
	automobile exhaust, tyre wear, lubricating oil and grease, bearing wear, brake linings, rubber, concrete, paint manufacturing, battery manufacturing, insecticides, phosphate fertilisers, sewage sludges
Zn	Zinc coating to prevent rust, in dry cell batteries, hazardous waste, paint, rubber, dyes, wood preservatives, ointments, phosphate fertiliser.

All elements are naturally occurring, except ‘CCA’.

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